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SECRET

MINUTES
of the Fifth
EXPLOSIVES SAFETY SEMINAR
on
HIGH-ENERGY SOLID PROPELLANTS

Held at the
Miramar Hotel, Santa Monica, California
on
20-21-22 August 1963

This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, U.S.C., Secs. 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

Armed Services Explosives Safety Board
Washington 25, D. C.

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PREFACE

Most of the discussion at the Seminar required no security classification. Certain discussions were classified "Confidential." Each page of these minutes has been stamped to indicate whether or not it contains "Confidential" information or is "Unclassified."

Participants were encouraged to present their own viewpoints. In some cases speakers described practices which differed from those in common use in the explosives industry. The inclusion of such comments in these minutes does not imply that they represent the viewpoint of the Armed Services Explosives Safety Board.

Further exchange of information on how to prevent explosive accidents is encouraged. It is suggested that any questions on portions of discussions be directed to the appropriate speakers, or their sponsoring agencies, rather than to the Armed Services Explosives Safety Board. This will expedite answers and will promote direct exchange of information between principals, which can be so effective in promoting safety.

Please advise the Armed Services Explosives Safety Board of any corrections to be made in these minutes, and errata sheets will be prepared.

The contribution to the cause of promoting explosives safety, by those who devoted valuable time and effort to this Seminar, is very much appreciated.

Leland S. McCants

LELAND S. McCANTS
Colonel, USAF
Chairman
Armed Services Explosives Safety Board

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Minutes of the

Fifth Annual

EXPLOSIVES SAFETY SEMINAR ON HIGH ENERGY SOLID PROPELLANTS

Miramar Hotel
Santa Monica, California

20-21-22 August 1963

Sponsor

Armed Services Explosives Safety Board

Host

United States Navy
Pacific Missile Range
Point Mugu, California

Col. Leland S. McCants, USAF, Chairman, ASESB: Gentlemen, on behalf of the Armed Services Explosives Safety Board, I would like to tell you, as one old country boy to another group of country boys, we are most happy to have you with us again. To see so many familiar faces and friends, is a real pleasure. As many of you gentlemen know, the ASESB Seminar has a different host each year. In 1961, the Air Force was our host and the meeting was held at Riverside, California. In 1962, NASA was our host and our Seminar was held at Langley Air Force Base, Virginia. This year our host is the United States Navy and on behalf of that noble Service, Capt. R. J. Teich is with us this morning to welcome each of you to this Fifth Annual Explosives Seminar sponsored by the Armed Services Explosives Safety Board. Capt. Teich is a native of Philadelphia; he graduated from the Drexel Institute of Technology in 1937 as Electrical Engineer. He was first commissioned as a Second Lieutenant in Infantry, but in 1937 he received the ungarbled word and became a Naval Aviation Cadet. Upon completion of his flight training in August 1937, he was sworn in as a Navy Ensign. Capt. Teich had both shipboard and flying duty in the Pacific during WW II and was awarded the Distinguished Flying Cross for action against the Japanese Forces in the Solomon Islands area in October of that year. Subsequent to the war, Capt. Teich's Naval career has been oriented in the main toward the research and development of Naval weapons systems. Specifically, he has been head of the Test Department, Naval Aviation Ordnance Test Station, Chincoteague, Va.; Engineering Liaison Officer for SCAR-1, and associated with the air-to-air missile program, Great Neck, Long Island. He has been the Vice Commander of the Pacific Missile Range, Point Mugu, California since January of 1962. Gentlemen, in short, it gives me great pleasure at this time to present to you Capt. Teich.

Capt. R. J. Teich, USN, Vice Commander, Pacific Missile Range: Col. McCants, members of the Armed Services Explosives Safety Board and distinguished guests. On behalf of Admiral Clark, the Commander of the Pacific Missile Range, it's indeed a pleasure to welcome you all here to this 5th Annual Explosives Safety Seminar. Since last February when the Chief of the Bureau of Naval Weapons first expressed interest in having the Range sponsor your meeting, Admiral Clark, and we at the Pacific Missile Range, have been looking forward to participating. It is unfortunate that Admiral Clark can't be with us this morning; however, he has asked me to convey to you his regrets and expresses sincere best wishes for a successful meeting. We of the Pacific Missile Range have a great interest in insuring the furtherance of the state of the art of explosives safety, not only through the management of safety programs and as a member of the Range Commanders Conference, but also by working closely with the Naval Missile Test Center at Point Mugu which functions for the Bureau of Naval Weapons in the research and development field. The Pacific Missile Range

supports the needs of varied range users and at the same time works closely with the Naval Missile Center on a cross-service basis so far as the use of ideas and facilities are concerned. Any range is vitally concerned with safety problems since the Department of Defense has given the range commanders the responsibility for safeguarding life and property with respect to his range operations. Frequently, the range commander is faced with conflicting requirements. It is the policy of the command not to unduly hamper the efforts and objectives of the range users; however, on the other hand the range users can't be permitted to take unjustifiable risks in executing a given program. To illustrate, let me show you a film clip. (Showed film and made appropriate remarks.)

The Range Commanders are vitally concerned with these problems and are continually striving for the standardization of safety criteria as well as other matters such as planning and instrumentation. I'd like to take this opportunity to mention our Range Commander's Conference as a matter of interest to some of you who may not be familiar with it. I know that there are several committee members here with us today. To utilize the maximum experience that we gain from range operations, the range commanders have established an informal organization called the Range Commander's Conference. I say informal because it's established on a purely voluntary basis, it consists of the range commanders of the national ranges, White Sands Missile Range, Atlantic Missile Range and the Pacific Missile Range and also the Service ranges which are the Naval Ordnance Test Station, China Lake, Air Proving Ground Center and the Air Force Flight Test Center. The range commanders meet twice a year with other groups. One of them is the Inter-Range Missile and Ground Safety Group which is of particular interest to you. I note that Mr. Ullian is on the program here this morning from the Air Force Missile Test Center. He will present AMR launch aborts here later this morning. Cdr. Hopkins one of our hosts here at PMR is a member of this Conference. The charter objectives of this Conference are to systematically provide and disseminate information currently pertinent to missile ground safety in the interest of establishing standard ground safety procedures at all ranges insofar as possible and the specific responsibilities are to develop a standardized hazard classification for propellants, investigate potential blast areas for combinations of liquid propellants and oxidizers, investigate potential RF hazards of electrical explosive devices, develop new control procedures for handling minor ordnance devices performing a switching function and develop a more meaningful way of categorizing toxicity of propellants, to standardize on forms for requesting information pertaining to the hazards and establish equivalency factors for new explosives.

Reviewing these responsibilities makes it very evident why we are happy here at the Pacific Missile Range to participate in the Seminar

and the supporting of related studies of programs. Matters of a particular recent concern are the RF immunity criteria for electrically initiated ordnance systems, toxicity problems associated with the new high energy fuels and radiological safety associated with the employment of SNAP devices which may involve local and atmospheric contamination. At a meeting such as this, we hope that new ideas and concepts can be developed which could provide maximum range safety, at the same time permitting the range users to carry out efficient operations. I know that you have a full and most interesting agenda for these three days and I hope and I am sure that it can only prove profitable. We hope that this fifth session of the Seminar will be highly successful. I want to thank you for coming and I hope you'll enjoy your short stay here in sunny California.

Col. McCants: Capt. Teich, we certainly appreciate your presence here with us today and are most grateful for the efforts of both yourself and your people in making this fine meeting possible.

Mr. Henry N. Marsh
Senior Vice President, American Ordnance Association

Having had a part in the conception of the idea, I take some pride in being here at this the Fifth Explosives Safety Seminar on High Energy Solid Propellants. It is a pleasure to see so many of that small group who gathered for the first session with the Navy at Indian Head in 1959, and have kept on coming to the later sessions with the Army at Redstone in 1960, with the Air Force at Riverside in 1961, with NASA at Langley in 1962, and now completing the circle with the Navy here at Santa Monica.

The attendance has increased each year - about in step with the rapid growth of this industry - and we welcome the newcomers attending their first session. Perhaps my brief remarks are directed more to them, but maybe it won't hurt to remind the old-timers as well that our goal in these meetings is to exchange experiences in order that we may insure maximum safety in this dangerous work. In that way, do our best to save lives and property, to save our own income taxes, for we pay for every accident, and to achieve maximum state of readiness for our country.

We fail in our efforts if anyone here holds back information which, if disclosed, might save a life in his own or in a competitors plant. Sure it is embarrassing to tell others of crude mistakes we may have made, or of faulty judgments that have proven disastrous. Disclose them - help others to avoid repeating the experience. This was the all-important job assigned to me.

I am taking advantage of this opportunity to say a word or two about the American Ordnance Association. As you see in the program, I am one of its Vice Presidents. As I look around I see many people whom I know are members but in a group like this every person in the room should be a member. Your goal to improve the U. S. state of readiness is the Association's major goal. Let me tell you a bit about it.

The American Ordnance Association is a patriotic, educational, scientific, non political and non-profit organization of more than 44,000 American citizens dedicated to scientific and industrial preparedness for the common defense of the U. S. We limit our activities to the field of weapons technology, production and logistics and over 900 concerns working in that field support the Association, though AOA is primarily an organization of individuals.

The headlines every day tell something - good, bad, or indifferent - about America's armament. Yet few of our fellow citizens realize the billions of hours of hard work that go into the strengthening of our Nation's defense. The tremendous efforts in research, in planning, in production, in distribution and maintenance by our armed forces in the field and by industry in factories, laboratories, and in Service have but one objective - a strong defense, second to none. The American Ordnance Association plays a vital part in the end result.

Of most interest to this group are the technical operations handled in some 15 divisions such as Bomb, Warhead and Artillery Ammunition Division; Missiles and Astronautics, Underwater Ordnance, Small Arms and Small Arms Ammunition Division. These are further divided into some 70 sections, each of which is composed of a group of specialists in the design and production of a special group of product such as Cartridge Case Section, Military Pyrotechnics Section, Guidance and Control Section, Machine Gun Section, Underwater Missile Section, and the Propellants and Explosives Section, of which our good Dr. Ball, who is present, is the chairman. These sections, with the blessing of the Department of Defense, meet whenever necessary from one to five times a year to be brought up-to-date on new developments and to consider problems and difficulties presented by Army, Navy and Air Force, and often are able to give material help and solve the problems.

Each of you should support this organization by your membership - only nominal in cost, $5.00 per year, or $12.50 for three years - for which you receive ORDNANCE magazine, recognized world-wide as the best publication on ordnance anywhere and a number of other publications. Many of you should be serving on technical divisions and sections to help solve these problems for Defense.

Many of the members come from industry, but there is also a large number of full-time employees and officers of the Army, Navy and Air Force who get into AOA at a bargain, as they only have to pay $4.00 per year or $10.00 for three years for dues.

To those of you who work anywhere in ordnance production, or research and development, check up and see that your company's name appears on the Honor Roll of Industrial Preparedness, if it isn't already there.

Mr. Bruce M. Docherty
Assistant General Counsel, Office, Secretary of the Army

Each year the General Counsel of the Army has been asked to make an attorney available for attendance at the Seminar on High Energy Solid Propellants. Those of you who have been at prior Seminars will remember that Mr. Donald E. Miller represented the Office of the General Counsel. Don is no longer in Government service but is now Assistant General Counsel of Fairchild Stratos, Hagerstown, Maryland. That is the reason he is not here with you today. In past years Don has explained in some detail the reasons for the presence of a Government lawyer at these Seminars. Let me restate those reasons briefly. The President recognizes that information and advice obtained through activities such as this Seminar are beneficial to the operations of the Government. He has prescribed uniform standards for the Departments and Agencies of the Government to follow in order that committees and similar groups sponsored by the Government shall function at all times in consonance with the antitrust and conflict of interest laws. This Seminar is of course being conducted in accordance with the standards applicable to this type of meeting. It is felt, however, that a Government attorney should be present as an added protection to the Government and all participants. I am not here to prevent the full and free exchange of information. That would defeat the purpose of the Seminar. The primary reason for my presence is to guard against the inadvertent consideration of any subject which might bring the Seminar within some aspect of the antitrust laws. This is not likely in view of the rules under which the Seminar is held and the excellent manner in which these Seminars are always conducted. The agenda has been prepared with a view to permitting free discussion of the important topics to be considered. I will be present throughout all the sessions. If at any time I think we are straying into any area which should be avoided I will call this to the Chairman's attention. Otherwise I will remain quiet and absorb as much as possible of the very important information which I know will be forthcoming here.

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Col. Leland S. McCants, USAF, Chairman
Armed Services Explosives Safety Board

Gentlemen, my two years assignment with the Armed Services Explosives Safety Board has revealed to me that many of our Service and industry associates are in need of information regarding the Board; its capabilities and more importantly perhaps its limitations. I appreciate the opportunity afforded to briefly apprise you of our operations.

The afternoon of 10 July 1926 was very similar to many previous Saturday afternoons at an ammunition depot of the United States Navy. An electrical storm was in its formative stages. The time was 1715 hours.

Suddenly, a jagged blade of lightning stabbed magazine no. 8 containing approximately 670,000 pounds of explosives - the rest is history, and the incident has long been known as the Lake Denmark Explosion. A significant segment of the Navy's emergency mobilization potential was wiped out in a series of flashes - 3.2 million pounds of explosives detonated - 21 individuals died, 52 were injured. The Navy and the adjacent Army facility suffered a loss approximating $75,000,000. Loss of life would undoubtedly have been in the thousands except for the fact that the work-day had ended at noon and those normally working were at home.

Thus, was born the Armed Services Explosives Safety Board. In brief, the Congress initiated a prompt inquiry into this incident. A Joint Board of Officers was appointed from the War and Navy Departments. These officers were charged with the responsibility of surveying all explosives locations world-wide and recommending corrective action where hazardous conditions were determined to constitute a menace to either life or property. In addition, a special House Sub-committee held extended hearings prior to recommending enabling legislation which was passed by the 70th Congress (1928). In 1956 this initial legislation was reaffirmed by the 84th Congress and specifically extended to include the USAF and Marine Corps.

The Armed Services Explosives Safety Board is organized and functions in accordance with a Directive issued by the Secretary of Defense. This Directive provides that the ASESB shall provide impartial and objective advice to the Secretary of Defense and the Secretaries of the Military Departments on ammunition and explosives manufacturing, testing, handling, transportation, storage and siting with special attention to preventing conditions that will endanger life and property within and outside DOD installations. For approximately a year we have been engaged in writing and coordinating a new

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DOD Directive clearly setting forth our responsibilities. I am most happy to advise that this new directive was approved by the Secretary of Defense on 25 July 1963. We have brought with us to this Seminar, a limited number of copies for distribution. In the event you desire but are unable to obtain a copy, please make request to the Board and it shall be promptly forwarded.

Chairmanship of the Board is currently rotated among the three Military Departments each three years. Appointments are made by the appropriate Service Secretary. My appointment was effective 1 September 1962 and followed an Army Chairmanship. The formal Board consists of the Chairman and the three Service Members and their designated alternates.

a. Capt. Oscar F. Dreyer, Commanding Officer, Naval Propellant Plant, Indian Head, Maryland is the current Navy Board Member.

b. Col. Robert L. Elwell, currently assigned the Inspector General's office in Washington is the present Air Force Board Member.

c. Col. Joseph M. Richardson, Army Materiel Command, Washington, D. C. is the Army Board Member.

These appointees have the vote privilege on matters before the Board. The Chairman exercises his voting rights only when the voting is not unanimous among the three Service Members. Aside from the formal Board just described, I am assisted in the execution of my duties by a permanent Staff consisting of a Senior Army and Navy Officer and explosives safety engineers (GS-15). The Staff are not members of the formal Board, therefore, do not have voting privileges. The Board meets at the call of the Chairman and official matters requiring formal Board attention normally are presented by the Staff accompanied by their recommendations as appropriate. Service Members may also, and frequently do, introduce matters for consideration.

Within the ASESB organization there is a Survey Division, whose responsibility it is to conduct scheduled field surveys of all DOD installations world-wide, wherever ammunition and explosives are handled, manufactured or stored. Appropriate industrial facilities, under contract to a Military Department, are included in this survey effort. Survey findings are reduced to writing and provided the Military Department concerned. Reports pertaining to contractor facilities are routed to such facility through the appropriate Service. Upon receipt, by the Board, of Service comments, to a given survey report, the Board Staff determines whether or not a requirement exists for advising the Service Secretary. Minor deficiencies are not

reported to the Secretary whereas serious hazards, endangering either life or property, are reported in accordance with the DOD Directive governing our operations.

In addition to our Survey Division we have a Technical Division whose primary concern is:

a. Maintaining close liaison with all three Services, industry and allied Governments in order to keep abreast of the science of explosives behavior and the safety considerations dictated thereby, and,

b. Reviewing all general plans for the construction of facilities wherein the handling, transportation and storage of military explosives and ammunition is a consideration.

c. The Technical Division, in addition, receives and evaluates accident and test data from any and all sources for the purpose of keeping advised, advising others, and determining the timeliness of proposing new or revised explosives standards. Many of you will recall that the ASESB, during 1961, joined with a large segment of the explosives industry in establishing an accident exchange program with the Board as the exchange focal point. This program is still active, thanks to many of you, and we are told has, in many instances provided a splendid service to some of the participants.

In this connection, and just in passing, I might congratulate some of you on the splendid safety records you're maintaining - we've not received a single incident report from some of you since the beginning of this information exchange program. The Board strongly encourages the free and unrestricted exchange of explosives research accident and incident information. I stress pertinent incident information since a mere incident today may well be the serious production destroying accident tomorrow. It is unfortunate but true that much of our progress, through the years in explosives safety, has been made only following a thorough analysis of accident information. Accidents represent experience and we all normally learn quickly and thoroughly as a result of such exposures provided we are not among the casualties. Without a steady flow of this information, we of the Board are handicapped in our ability to provide you with the technical advisory service which you may require. We should like to offer you access to both our technical staff and our voluminous files, as the requirement arises, providing, of course, your security status is properly certified in advance of your request for assistance.

d. The Technical Division is also responsible for directing the activities of work groups established by the Board Chairman. Due to the limited technical staff of the Board, extensive use must, of

necessity, be made of available professional talents nation-wide in work group efforts. These include personnel nominated by the three Military Departments and, as appropriate, industry representatives. When appointed to a work group effort these nominees become temporarily a part of the Board's official family.

Allow me to briefly acquaint you with a few of our work group efforts in which you may have interest.

a. The product of a work group established during September 1961, to develop quantity-distance criteria for the bulk storage of liquid propellants, is currently undergoing coordination within the Military Departments. You will hear more about this during the Seminar.

b. Since February of this year we have been actively engaged in a work group effort aimed at revising and updating "Special Instructions to Drivers of Motor Vehicles Transporting Explosives and Certain Other Dangerous Articles." Subsequent to the establishment of this work group the Air Force and Navy requested expansion of the effort to include pilots of aircraft transporting such materiel.

c. In April 1962 we formed a Work Group to Study Fragmentation Distance Requirements and Hazards for Large Missile and Weapons Systems. Mr. Perkins of the ASESB Staff will review the progress of this effort later in the Seminar.

d. The ASESB working, over a period approximating two years, with funding provided by the three Military Departments and the Defense Atomic Support Agency, has conducted a Dividing Wall Test Program with which I believe the majority of you are acquainted. Widespread interest has been reflected in the data available from these tests and I am able to report that we are currently producing an unclassified color film reflecting this work. Arrangements are being made whereby these films may be made available to industry thru either loan or sale. I regret that I cannot give you complete details or availability dates at this time.

The revision and/or establishment of DOD standards governing the handling, transportation, and storage of ammunition and explosives represents one of our most complicated and frustrating endeavors. Almost everyone outwardly reflects a desire for explosives safety guidance in the form of both recognized and proven criteria; inwardly, however, many of these same individuals have such a passionate desire for freedom of action that this desire overwhelmingly transcends the other.

Let us briefly look at the mechanics of establishing a new or revising an existing explosive safety standard.

a. First, the proposal may be generated and presented to the Board from a number of sources - the Military Departments, industry, the Board Staff.

b. Secondly, the proposal is introduced into a formal Board meeting.

c. Thirdly, the Board may do one of several things, specifically:

(1) They may consider the available technical data sufficient to support the proposal and vote unanimously therefor, or,

(2) They may consider the proposal worthy of study by a work group and so recommend to the Chairman, or lastly,

(3) They may fail, following all appropriate actions, to reach unanimous agreement due to myriad reasons. In such instance the Chairman may exercise his right to cast the deciding vote thus progressing the state of the art, as it pertains to explosives safety provided, in his opinion, the technical data available warrants disregarding the opposition. The dissenting Service, in such instance, may execute a minority paper and appeal the Chairman's decision to the Secretary of Defense, whose decision is final.

The point I should like to stress before continuing is that the Board is neither czar nor dictator in the field of explosives - it is an advisory group and neither has nor seeks directive authority. In short we work with people, continuously encouraging them in the development and sharing of data which will benefit all concerned. As data in any given area appears to be sufficiently complete, a coordinated effort is initiated, utilizing many of your expert talents to assist us. We are frequently not satisfied with the pace of our progress any more than you are, but must face sobering facts when a thorough analysis of all available data clearly reflects that there simply is not enough to support the issuance of a standard yardstick for a given operation. Contrary to some opinions we do not wake up bright-eyed and bushy-tailed on a given morning and decree that this is "standards establishment" day. Neither do we have nor seek the authority to settle explosives safety controversies which arise between a Military Department and its contractors unless such Service requests our intervention.

The Board, as many of you are aware, has only a very limited technical staff and our testing capabilities are correspondingly limited. In spite of this, we have been able, through surveys, coordinated testing, research and work group efforts, to make

significant contributions to explosives safety. Within our Staff capabilities and available funding, these efforts will be continued. We would encourage you to do likewise for this is the only way we will obtain many answers sorely needed to questions confronting us daily.

Gentlemen, this presentation has afforded a very brief glimpse of our organization. I hope it has been both informative and enlightening and that the information will serve you well in the months ahead.

Department of Defense Directive

SUBJECT: The Armed Services Explosives Safety Board

Reference: (a) DoD Directive 5154.4, subject as above, November 21, 1953 (hereby cancelled)

I. PURPOSE

Pursuant to the authority vested in the Secretary of Defense and in accordance with the provisions of 10 USC 172, this directive establishes the Armed Services Explosives Safety Board within the Department of Defense as a joint agency of the three Military Departments and subject to the direction, authority and control of the Secretary of Defense. Its composition, functions and responsibilities, authority, relationships and administration will be as prescribed below.

II. CANCELLATION

Reference (a) is hereby cancelled.

III. APPLICABILITY

This directive applies to all DoD components world-wide and covers facilities under United States jurisdiction located within the United States and overseas wherever ammunition and explosives are manufactured, tested, handled, transported or stored while under the custody of the DoD.

IV. DEFINITION

A. As used herein, ammunition and explosives includes (but is not necessarily limited to) all items of ammunition; chemical propellants, liquid and solid; high and low explosives; guided missiles, warheads; devices; signals; components thereof, including chemical, biological and radiological (CBR) fillers; and substances associated therewith presenting real or potential hazards to life and property.

Note: The Board does not have cognizance over:

1. liquid fuels and oxidizers other than for use with missiles, guns, rockets and similar items.

2. nuclear bombs, warheads, and devices, except in an advisory capacity for considerations concerned with blast, fire, and non-nuclear fragment hazards associated with the chemical high explosives contained therein. All other considerations involving nuclear weapons will be determined in accordance with established agreements and directives.

3. the bio-medical aspects of determining tolerable exposure levels and storage or handling criteria, for CBR hazards.

4. wholly inert items.)

B. As used herein, "administrative support" is defined to include budgeting, funding, fiscal control, manpower control and utilization, personnel administration, security administration, space, facilities, supplies and other required administrative provisions and services.

V. COMPOSITION

A. The ASESB shall be composed of:

1. A Chairman.

2. A representative from each of the Military Departments.

B. The ASESB shall be supported by a permanent Secretariat.

VI. FUNCTIONS AND RESPONSIBILITIES

A. Under the policy direction and program guidance of the Assistant Secretary of Defense (Installations and Logistics), and in consonance with other DoD policies and directives, the ASESB shall:

1. Provide impartial and objective advice to the Secretary of Defense and the Secretaries of the Military Departments on ammunition and explosives manufacturing, testing, handling, transportation, storage and siting with special attention to preventing conditions that will endanger life and property within and outside DoD installations.

2. Establish as appropriate, or coordinate the establishment and periodic revision of Safety Standards designed to prevent or correct hazardous conditions associated with ammunition and explosives and maintain such standards current with modern weapons systems and develop the optimum degree of uniformity for controlling similar or like hazards.

3. Maintain liaison with other Government departments, allied Governments, and industrial organizations having a mutual interest or responsibility in safety matters involving ammunition and explosives.

4. Keep informed of Armed Services' safety problems relating to ammunition and explosives development, manufacture, testing, handling, transportation, storage, maintenance, salvage, and disposal.

5. Survey, study and evaluate activities to determine compliance with ammunition and explosives safety standards and to detect conditions which could result in undue loss of life or damage to property within and outside Department of Defense installations.

6. Review and analyze reports, data and information from all sources, in which ammunition and explosives hazards, accidents, and safety (nuclear excepted) are involved; making maximum use of existing knowledge and data for the early recognition of hazardous conditions; making appropriate recommendations to proper authorities for the establishment or revision of timely standards.

7. Review and evaluate all general site plans for the construction and modification of pertinent ammunition and explosives sites to enable the Board to give timely, impartial and objective advice on the safety of these sites as well as their relationship to other operating locations to the extent that ammunition and explosives are involved.

8. Undertake such investigations, studies and test programs, concerning ammunition and explosives hazards as the Secretary of Defense, the Secretaries of the Military Departments, or other appropriate authority may request.

9. Perform such other duties as may be assigned by the ASD(I&L), or with his approval, by the Secretaries of the Military Departments.

B. The Secretaries of the Military Departments, or their designees, shall:

1. Provide the ASESB with information and support necessary to discharge its assigned responsibilities and functions.

2. Submit to the ASESB for review and comment general site plans for construction or modification of pertinent sites involving ammunition and explosives and outlining the type and character of the proposed construction.

3. Conduct research and development programs and projects to develop safety standards, practices, procedures, and devices for ammunition and explosives, and provide the ASESB with periodic reports on the progress thereof.

4. Set interim safety standards for the manufacture, storage, and handling of ammunition and explosives pending the establishment of DoD-wide standards.

5. Implement the DoD safety standards established by the ASESB. Inability to comply with such standards for strategic or other impelling reasons may be made the subject of a specific waiver or exemption issued by that Military Department. Responsibility for such waivers or exemptions rests with the Secretary of the Military Department granting such waivers or exemptions.

6. Provide qualified personnel when requested by the Chairman, ASESB, to ASESB working groups.

C. The Secretary of the Army or his designee as Executive Agent for the administrative support of the Board as defined above, will determine and provide adequate administrative support for the operation of the Board and its Secretariat.

VII. AUTHORITY

A. To discharge the functions and responsibilities assigned herein, the Chairman, ASESB, shall:

1. Preside at ASESB meetings, or, in his absence, designate an appropriate member to act in his stead.

2. Determine the internal organization of the ASESB and its Secretariats' procedure; and direct the activities of the Board Members and the Secretariat.

3. Establish a reporting system to provide the Secreta[illegible] Defense and the Secretaries of the Military Departments with current information on all matters falling within ASESB jurisdiction.

4. Exercise the power of decision, as appropriate, on any matter within ASESB jurisdiction, on which other ASESB Members are not unanimous. With respect to any such decision of the Chairman, any ASESB Member may initiate a written appeal therefrom through the Secretary of his Military Department to the Assistant Secretary of Defense (I&L) for review and final decision.

5. Establish and direct the activities of temporary working groups, as appropriate, to assist the ASESB.

6. Determine what coordination is required on matters referred to the ASESB.

B. The Chairman and the Board Members are authorized and expected to exercise free and unrestricted access to, and have direct communication with, all elements of DoD as well as with other governmental, foreign, and private organizations having a mutual interest or responsibility in safety matters involving ammunition and explosives. With regard to nuclear weapons, access and communication will be in accordance with established procedures utilizing existing agencies.

VIII. ADMINISTRATION

A. The Chairman, ASESB, shall be selected and appointed by the Assistant Secretary of Defense (Installations and Logistics) from qualified officers of the rank of Colonel or Captain (Navy), or higher, nominated by the Secretaries of the Military Departments. The office of Chairman, ASESB, shall be rotated equitably among the Military Departments. His term will be for a period of three years and his effectiveness of performance will be evaluated by the ASD(I&L). Prior to assuming office, the Chairman will have served as a member of the Board Secretariat for a period of approximately twelve months. The Chairman shall be responsible to the ASD(I&L) for policy direction and program guidance and shall receive administrative support from the Secretary of the Army or his designee as set forth herein.

B. The Secretaries of the Military Departments shall each select and assign one qualified officer of the rank of Colonel or Captain (Navy), or higher, to serve as a Member of the Board. The Secretaries shall each also assign an alternate who in the absence of his principal, will act for the Member, with plenary powers.

C. The Armed Services Explosives Safety Board Secretariat shall be composed of such qualified military and civilian personnel as the Chairman, with the approval of the ASD(I&L), shall determine are required to effectively fulfill ASESB responsibilities.

1. Military staff members shall consist of at least one individual from each Military Department, having appropriate rank and experience, and acceptable to the Chairman, ASESB. Military personnel shall be assigned to the ASESB Secretariat on a full-time basis, and during such assignment shall be responsible to the Chairman for performance of duty and efficiency ratings.

2. Civilian ASESB Secretariat personnel shall be provided by the Secretary of the Army.

3. Applicants for technical Secretariat positions will be selected by the Chairman and jointly reviewed by the Board Members.

D. The Secretary of the Army may designate and assign to the Under Secretary or an Assistant Secretary of the Army responsibilities for the day-to-day supervision of the administrative activities of the Board.

IX. IMPLEMENTATION AND EFFECTIVE DATE

This directive is effective immediately. Implementation will be effected within 60 days of this date and three copies of the implementing instructions forwarded to the Assistant Secretary of Defense (Installations and Logistics).

Roswell Gilpatric

Deputy Secretary of Defense

INVESTIGATING ACCIDENTS

by
Louis Jezek
Hq. U. S. Army Materiel Command

Prior to World War II, the Army did not have a definite system for accident reporting such as we have today. In many instances, if personnel casualties were not high or if large quantities of munitions were not involved, a formal investigation was not conducted.

Today, procedures have been established whereby certain accidents must be reported immediately by telephone. The types of explosions and serious accidents that will be reported are outlined in AMC Regulations.

The reasons for reporting of such accidents are to permit prompt notification of other facilities that may be conducting similar operations of the known hazards, and to permit the dispatch of safety engineers to the scene as soon as possible. Valuable information may be lost in the shuffle if a delay should occur between the time of the accident and the time the investigation starts.

The primary purpose of accident investigations is to determine the specific cause or causes so that corrective action can be taken to prevent similar accidents.

When an individual or a board has been appointed to investigate the circumstances surrounding an accident, the following factors are considered to be important if a truly worthwhile investigation is to be made:

a. Persons assigned to conduct the investigation should be familiar with the operations or circumstances involved. Experts or consultants should be called upon when highly technical problems arise. A good investigator seeks reasons for the accident not alibis.

b. Investigating personnel should not pre-judge the accident before a full evaluation of the circumstances is accomplished.

c. Witnesses being interviewed, should be put at ease. They should be advised as informally as possible why the investigation is being conducted.

d. Board members conducting an investigation should determine all the facts about the accident as well as determining the pecuniary

responsibilities. Recommendations should be made to prevent recurrence. In many instances, it is apparent that tvo little emphasis is placed on factfinding and too much upon placing the blame on individuals.

It is the policy of AMC to dispatch safety engineers to the scene whenever a major disaster is reported.

Investigating personnel act as observers to obtain cause and effect information. This information is phoned to the Safety Division as soon as possible. This is accomplished in order that important information may be transmitted to other facilities without delay. Under no circumstances are these investigators permitted to interfere with a local board appointed to investigate the disaster nor will they accept any of the responsibilities of the local commander. However, assistance may be given to the investigating board or the commander, if requested. After the incident has been investigated, the engineer returns and a report of the incident is written.

To assist the person making the investigation, an outline of investigation procedures is used. Copies of this procedure will be available to you later on. Items listed in the outline indicate sequences of investigation, specific items to be checked and information to be obtained for report. Certain items of information may not apply in all cases and sequence of investigation may not be practical in all cases. This is intended to be used as a guide so that valuable information available at the scene of an incident or from witnesses and injured persons will not be overlooked.

1. Examination of scene. Prevent disturbing of debris. Determine nature of incident.

a. Locate exact seat of incident.

b. Determine sequence of explosions, course of fire and order of explosion.

c. Explosives, CBR agent or flammables involved.

(1) Nomenclature, Lot #, AIC
(2) Quantity
(3) Manufacturer

d. Persons exposed

(1) Number
(2) Exact location
(3) Names, ages, employment records

e. Radius of complete destruction (structures blasted to ground).

f. Radius of structural damage beyond economical repair.

g. Radius of reparable structural damage.

h. Range of general glass breakage.

i. Distance to which most missiles were projected; kind and weight of missiles.

j. Description of equipment damaged.

k. Area contaminated or scorched by fire.

l. Balance sheet of equipment to determine exactly where each item was located at instant of explosion, whether or not it belonged there.

m. Sketch of exact location of incident to scale. Show positions determined in 1d(2) and 1e, f, g, h and i. Show locations before and after explosion.

n. Distances of injured from seat of incident.

o. Distances of equipment from seat of incident.

p. Estimated property damage.

q. Estimated effects on production.

r. Location and nature of unexploded ammunition or explosive.

s. Effect of explosions on barricades. Description and location of barricade.

t. Size of crater formed and type of ground in which formed.

u. Heating equipment - type

(1) Steam or element temperature.

v. Lighting and power equipment. Proper type of hazard?

w. Photographs.

(1) Camera location, distance from objects, a sketch.
(2) Scale, right-angled, to show vertical and horizontal coordinates.
(3) Photograph bodies of dead in position found (do not cover bodies).

x. Sift remains for foreign articles.

y. Determine if any authorized person has visited scene before or since explosion.

2. Examination of bodies of dead, each listed separately.

a. Name, age and service record of victim.

b. Details of injuries; indicate on representative sketch of body.

c. Cause of death.

d. Cause of wounds, specific.

e. Course of wounding agent (to determine direction of flight).

f. Foreign material in wounds - tabulate.

g. Details of clothing and footwear remains.

h. Effectiveness of protective equipment.

3. Examination of injured, each listed separately.

a. Name, age and service record of injured.

b. Details of injuries.

c. Cause of wounds.

d. Course of wounding agents.

e. Foreign matter in wounds.

f. Details of damage to clothing.

g. Effectiveness of protective equipment.

h. Statements of injured.

i. Interrogation.

(1) Apparent location of first indication of trouble.
(2) Attitude of workers.
(3) Cause of trouble.
(4) Quantity of explosives or CBR agent present.
(5) Operations being performed.

(a) Deviations from normal.

(6) Previous troubles in operation.
(7) Observance of rules.
(8) Knowledge of rules.
(9) Apparent sequence of explosion or course of fire.
(10) Persons exposed.
(11) Exact location of such persons.

4. Witnesses, also first-aid personnel who may have spoken to victims who subsequently died.

a. Name, age and service record of witnesses.

b. Sworn statement in own words.

c. Interrogation.

(1) Apparent source of trouble.
(2) Exact position at time.
(3) Sounds heard.
(4) Visual observation.
(5) Attitude of workers.
(6) Operations performed.
(7) Cognizance of rules.
(8) Quantity of explosives.
(9) Action taken.
(10) Statements of injured.

5. Details of operation.

a. Obtain copy of SOP.

b. Operation at instant of trouble.

c. Succeeding operations.

d. Dust present?

(1) During operation.
(2) In case of concussion in room or adjoining room.

e. Nature of explosive.

(1) Friction sensitiveness.
(2) Shock sensitiveness.
(3) Static sensitiveness.
(4) Moisture sensitiveness.
(5) Familiarity of operators with characteristics.

f. Operating rules.

(1) Posted.
(2) Enforced.
(3) Satisfactory.

g. Treatment of explosive or CBR agent.

(1) Taking cognizance of its characteristics.

h. Clothing required and clothing actually worn.

i. Safety equipment provided (effectiveness).

j. Maintenance of equipment - was it satisfactory?

6. Supervisory Personnel.

a. Attitude.

b. Familiarity with operation.

c. Experience.

d. Opinions regarding cause.

(1) Basis for opinions.

7. Outside data.

a. Seismograph recordings.

b. Temperature.

c. Humidity.

d. Barometric changes.

e. Time determination.

f. Weather.

(1) Preceding the occurrence.
(2) At the time of occurrence.

g. Temperature of explosive storage preceding operation involved.

(1) Time in storage.
(2) Containers used.

h. Exposure of explosive to weather or atmosphere in room.

(1) Before going into operating room.
(2) During operations.

8. Summary.

a. Possible causes.

b. Refutation or substantiation of statements.

c. Significance of data.

d. Effectiveness of precautions.

9. Conclusions.

a. Cause.

b. Prevention.

10. Recommendations.

a. Covering basic principles.

b. Covering specific causes.

Col. Morong: In your comments I was interested in a remark that you made that the accident investigating board was going to attempt to establish a legal liability. This is a little unusual is it not?

Mr. Jezek: I don't think I mentioned legal liability, I mentioned pecuniary. They do that, they try to find out whether a person was criminally negligent or not. I just don't understand your question fully, would you repeat it?

Col. Morong: You said the accident investigating board was going to attempt to establish a pecuniary liability.

Mr. Jezek: That's right. If they can prove that some person was responsible for the accident, he can be made to pay for the damages, that's been done before, in some cases.

Col. Morong: This is a little different route than we follow in the Air Force, that's why I was interested in your remarks.

Mr. Jezek: Based on some of the comments that I have had from some of the Air Force people, you don't operate exactly like we do. As far as this litigation is concerned, I would like to mention that whenever you have a photographer that goes out to take pictures, please make sure that you have a photographer sign his name to the back of each photograph and the date and the time when the photograph was taken because in the event of litigation, that evidence is very necessary to be admitted in court. I think that when we had the investigation done at the Lewis, Indiana explosion, I think Col. Peter can back me up on this, we had the photographer sign the back of every one of the pictures that were taken.

Mr. Vondersmith: My question relates to your hand-out. In the procedure of investigating an incident, how far back prior to the incident do you normally go?

Mr. Jezek: That's up to the investigating board. I can site you an example of an accident that took place at Redstone Arsenal where a civilian truck driver ran into a train. They went back as far as the man's service record and found out that this man had suicidal tendencies when he was in the Army. As a matter of fact, he tried to kill himself twice. Whether this had any bearing on him smacking the side of a locomotive with a truck, I can't answer. It all depends on what the circumstances are.

Mr. Vondersmith: I was particularly interested in records on the maintenance of equipment.

Mr. Jezek: Yes, they should go back as far as possible, as a matter of fact, in some cases we have to go back three or four years. I know of a case where some cutters were cutting a pipe and the pipe had been lying around for about four years and they had to go back to find out where the pipe came from, what it was used on and everything else. If you have to go back that far to find out what caused the accident, you have to do that.

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SHOCK INDUCED SYMPATHETIC DETONATION IN SOLID EXPLOSIVE CHARGES

by
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Abstract

A study of the basic physical parameters for sympathetic initiation of high explosive receptor charges by the pressure pulse from a donor charge transmitted through barriers of air, steel, aluminum, lead, and copper has been conducted. A surface phenomenon, which has been shown to be a front of mechanical discontinuity supported by a chemically reacting core, has been observed to propagate at a constant, supersonic velocity. The core reaction is initiated provided the intensity of the incident pressure pulse is less than the detonation pressure of the explosive but above a threshold value which depends on the chemical composition and physical condition. The initial core reaction is a "low-order" chemical decomposition which produces a pressure considerably less than that associated with high-order detonation, and propagates at a supersonic rate, but much slower than a higher-order detonation. This reaction is confined to the central core of the explosive and its rate of propagation is determined by the intensity of the incident wave. The distances and times required for the reaction to change abruptly to high order detonation are uniquely determined, for a given explosive, by the intensity of the incident pressure wave. High order detonation is first observed at the surface of the charge coincident to the front of the mechanical discontinuity. However, the shape of that front, on emergence, indicates that initiation originated in the reacting core.

Invariably, for a considerable time after the beginning of the high-order reaction in the receptor charge, it propagates at a rate slightly greater than normal detonation rate.

While details of behavior vary with composition and geometry of the explosive, the qualitative features appear to be generally valid.

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Introduction

Studies have been made of the fundamental physical processes involved in the detonation reaction of solid explosives. These studies have led to an analysis of the parameters that control the sympathetic detonation of a receptor charge subjected to strong shocks transmitted through barriers of various materials. It is felt that these studies might lead to a fuller understanding of the detonation process and could also indicate a criterion of sensitivity based on physical quantities directly related to the explosive charges. Continuation of the research project reported formally first in a Ballistic Research Laboratories Report(1) in 1953 and subsequently in later reports(2,3) indicate the direction of this continued research with finer time and space resolution, employing new techniques for the investigation of the regime of transition from initiation to high-order detonation. Much of the earlier data were inferred from the observation of the surface conditions of receptor charges. The work covered by this report deals with the direct observations of the core reaction in the receptor. These new observations eliminate the errors and uncertainties introduced by the earlier inferences.

Experimental Procedure

Except for some preliminary experiments with internally cast resistance wires(4) all of the data were obtained from photographic records(5). Self-luminosity and auxiliary front lighting were used with streak-cameras, kerr-cell single exposure shutters and multi-frame, high repetition rate, framing cameras.

The charges were arranged as shown in Figure 1 and, except where noted, were cast 50/50 pentolite sticks of 3/4 inch square cross-section, 3 inches long. Barriers of air, steel, dural, copper, lead and plastic have been tested. However, most of the data presented in this report represent a variety of barrier thicknesses of air, lead and dural.

Data for initiation by pellet impact were obtained with steel discs, driven intact, at velocities ranging from 500 to 1500 meters per second by metal-padded explosive sticks.

Discussion-Specific Results

As a result of the methods for the determination of initial conditions in the receptor charges, the quantitative data obtained in these tests fall into three general categories, i.e., air-gap,

metal barrier and pellet impact. However, the conditions leading to high order detonation can be described by a single physical model.

1. Initiation by Shock Through Air Gaps

The earliest investigations of shock initiation were concerned primarily with air barriers, and the time "t" and distance "d" shown in Figure 2A, which is a typical streak-camera record, were the first observations made of the delay to detonation. More recent, front lighted records (Figure 2B) have shown that this time "t" consisted of at least two individual delays, i.e., the delay to ignition and the delay to high order detonation after ignition established a core reaction in the receptor stick. The direct measurements of the supersonic surface velocity[3] as a function of the width of the air gap in comparison with the velocities computed from the "t-d" data are shown in Figure 3.

For detonation induced by the air shock it is necessary to separate the contributions of peak pressure, impulse and possibly heat, to the reaction in the receptor. The pressure in the air shock at the face of the receptor is directly obtained from the Hugoniot relations for air, which are well known for the velocities involved. The pressure so obtained, cannot be used directly to obtain the pressure in the receptor, however. Theory and experiment both show that the peak pressure occurs when the high density detonation products, which are following closely behind and driving the air shock, impact the face of the receptor charge. A single rough measurement made at these Laboratories (by Mr. Boyd Taylor) of the pressure developed in a Plexiglas receptor separated by a 1 inch air gap from a standard pentolite donor yielded an estimate of 300,000 PSI. At this gap distance, the pressure in the incident air shock is about 8,500 PSI and, allowing for a maximum theoretical eight-fold magnification in the reflected shock from a perfectly rigid wall, the pressure at the receptor face could be expected not to exceed 68,000 PSI as a result of the shock impact. The quantitative data presented relate the surface velocity and the delay to detonation in the receptor to the pressure in the incident wave. Recomputing to include the results of the single test with the Plexiglas receptor will increase the magnitude of this pressure, and will throw the air gap data into agreement with the metal barrier data.

2. Initiation by Shock Through Metal Barriers

The delay time and distance to detonation in receptor charges have been studied as functions of both the barrier thickness and barrier material with lead, dural, copper, and steel. However,

sufficient data for quantitative as well as qualitative analysis have only been obtained with the lead and dural barriers.

Direct measurements of the pressure induced in the receptor charges could not be made with existing instrumentation and techniques. However, once the pressure in the barrier at the barrier-receptor interface is known, this information can be used with the extended high pressure Hugoniot curve published by Los Alamos(6). By use of the pin technique, Dr. Floyd Allison at Carnegie Institute of Technology supplied the free surface velocities of barrier materials driven by contact donor charges. Using the relationship:

$$P = \rho_o U_s U_p$$

where: P is pressure (dynes/cm^2)
ρ_o is barrier density (gms/cm^3)
U_s is shock velocity in the barrier (cm/sec)
U_p is the barrier particle velocity (cm/sec),
and is approximately 1/2 the free surface velocity,

the pressure transmitted to the receptor charge is computed. The relationship of the delay to detonation for lead and dural is shown as a function of these computed pressures in Figure 4.

To date, the pressure profile and consequently the impulse delivered to the receptor charge have not been measured. With new pressure transducer techniques, a program to determine values for this parameter is being initiated. However, the contribution of total impulse appears negligible in the comparison, shown in Figure 4, of data for two materials of widely different density and physical characteristics.

3. Initiation by Pellet Impact

Aluminum pads of various thickness were used on the ends of large explosive cylinders separating the charge and disc to be propelled. Tests were conducted with steel discs 1.5 inches in diameter and 0.125 inches thick weighing 28.32 grams with velocity of impact at the receptor ranging from 0.58 to 1.52 mm/μsec. Earlier evidence that peak pressure, not total energy delivered to the receptor, controlled the delays and velocities in the receptor led to the treatment of the plate as a free surface. Computations identical to those for metal barriers were made and the plot shown in Figure 5 indicates the close agreement of these data to those in metal barriers.

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It appears most likely that the excessive scatter in the impact data resulted from oblique collision of the plate with the end of the receptor. Additional testing of the effects of oblique impact is being conducted to amplify this possibility.

Discussion-General Results

An examination of the photographic exposures made in tests conducted with the air and metal barriers and impacting pellets made it immediately obvious that the initiation, the pre-detonation, and the "break-out" of high order detonation have the same physical characteristics for all these methods of transfer of energy to the receptor charge. Four conditions have been found to exist in the impacted receptors:

1. Detonation occurs with no measurable delay at the impacted face of the receptor.

2. A measurable supersonic surface shock of mechanical discontinuity proceeds at constant velocity in the receptor, and eventually high order detonation breaks out in this front.

3. A measurable supersonic surface shock of mechanical discontinuity proceeds at constant velocity for the entire length of the stick and high order detonation is not observed.

4. A measurable supersonic surface shock of mechanical discontinuity is observed to gradually decay and be no longer observable as it approaches sonic velocity. High-order detonation does not occur.

The first of these conditions was not covered in this study, and the results which follow are only related to 2, 3 and 4 above.

The observation of a supersonic shock along the surface of the charge, proceeding at constant velocity, requires that energy be fed into that shock. This indicates that a chemical reaction has been initiated in the receptor. The lack of observation of this reaction at the surface does not preclude its existence. With receptors cut to lengths equal to, shorter than and longer than that distance at which high order detonation would be expected to occur for a given barrier condition, the results shown in Figure 6, which is a composite of a series of streak-camera records, were obtained for the core reaction. The profile of this reacting core can be observed to be changing shape in these records. Figure 7 is a plot of the velocity of the reaction (measured in the direction of the axis of the charge) at the center of the charge and at various

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radial distances from the center, as indicated. The shape of the reacting core at any given time is directly related to the difference in velocity, which is highest at the axis of the charge and decreases with radial distance. The non-reactive surface shock is joined by a continuous extension of the shock profile of the reactive core, and has the lowest velocity observed during the pre-high-order detonation regime.

The velocity of the surface shock has been found to be constant in each record. However, the magnitude of this velocity is a function of the barrier conditions. The core velocity along the axis has been measured and also shown to be constant from the photographic record of charges of different lengths, and measured as constant in a given charge by the resistance wire method mentioned earlier(4). The magnitude of the axial velocity is also dependent on the barrier conditions.

The surface observation obtained for dural and lead barriers is plotted vs the transmitted pressure in the receptor charge (Figure 4), and it is indicated in this diagram that delay time and distance are directly dependent on pressure alone, and independent of impulse. A similar graph, Figure 3, is shown for air barriers but, as described under "Discussion" the pressure shown is that of the incident air shock. Figure 5 shows the similarity of data for pellet impact to those for metal barriers.

In over three hundred tests conducted, the velocity of the high-order detonation that is induced in the receptor has been invariably about 1 1/2% higher than the velocity of detonation in the donor sticks. In two of these receptor sticks the detonation velocity has dropped abruptly to its normal value. A valid physical explanation for this observation cannot be made on the basis of information obtained in these firings.

Conclusions

It follows from the results obtained with the air gaps, metal barriers and pellet impact studies of sympathetic initiation that a single physical model can be established for all of these conditions.

Although the nature of the initiation of the reaction is not known, there is no evidence to contradict the hot spot theory of Yoffe and Bowden(7). Allowing that the reaction does start by adiabatic compression of trapped gases, mechanical heating, or a combination of both, the volume of this reaction and, as a consequence, its pressure and propagation velocity, are functions of

the pressure of the initial shock transmitted to the receptor. As this reaction propagates internally, as seen in the results presented here, the rarefaction wave from the boundary is sufficiently strong to prevent surface detonation. However, the pressure of this internal shock is sufficiently great to manifest mechanical surface changes in the solid explosives, observable by front lighting techniques. When the rate of dissipation of energy in the rarefaction, the internal pressure builds up to a point at which a discontinuous jump to a high order detonation occurs in a manner similar to that proposed by Von Neumann[8]. However, in this case the reaction moves from an n=k Hugoniot, in which $1 > k > 0$, to the n=1 Hugoniot when the pressure reaches a value equal to that at the intersection of the n=k Hugoniot and the Chapman-Joguet plane. If the rate of energy release is such that the pressure does not build up at a rate higher than the rate of dissipation in the rarefaction, then the reaction either continues at a constant rate or at a decreasing rate until it is no longer detectable.

It is also concluded that the contribution to this reaction by the shock from a donor charge passing through a barrier to the receptor charge is a function of the initial pressure in the receptor. Although the significance of the total energy in the pressure pulse is not evident in these experiments it is being investigated further to determine its role in the total reaction.

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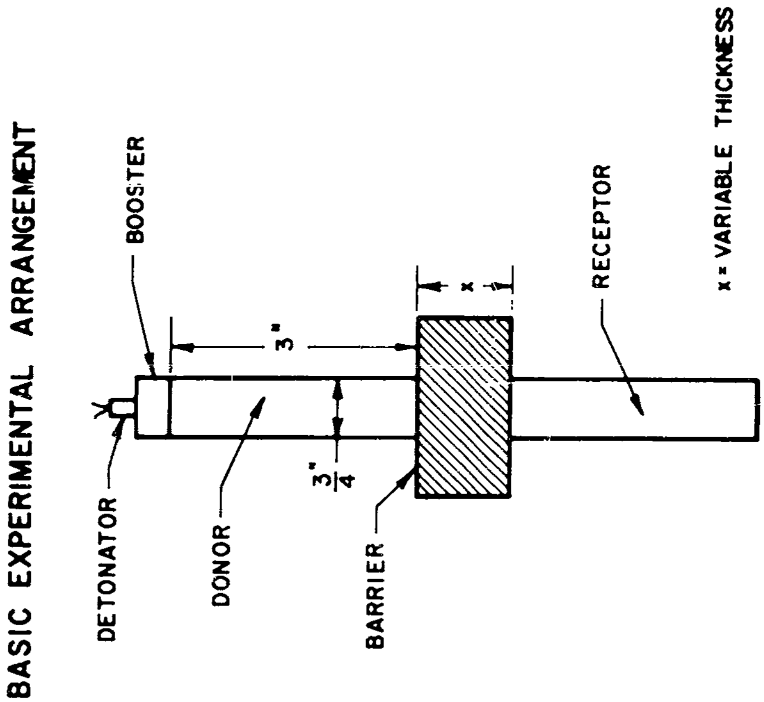

1- Experimental Arrangement of Charges

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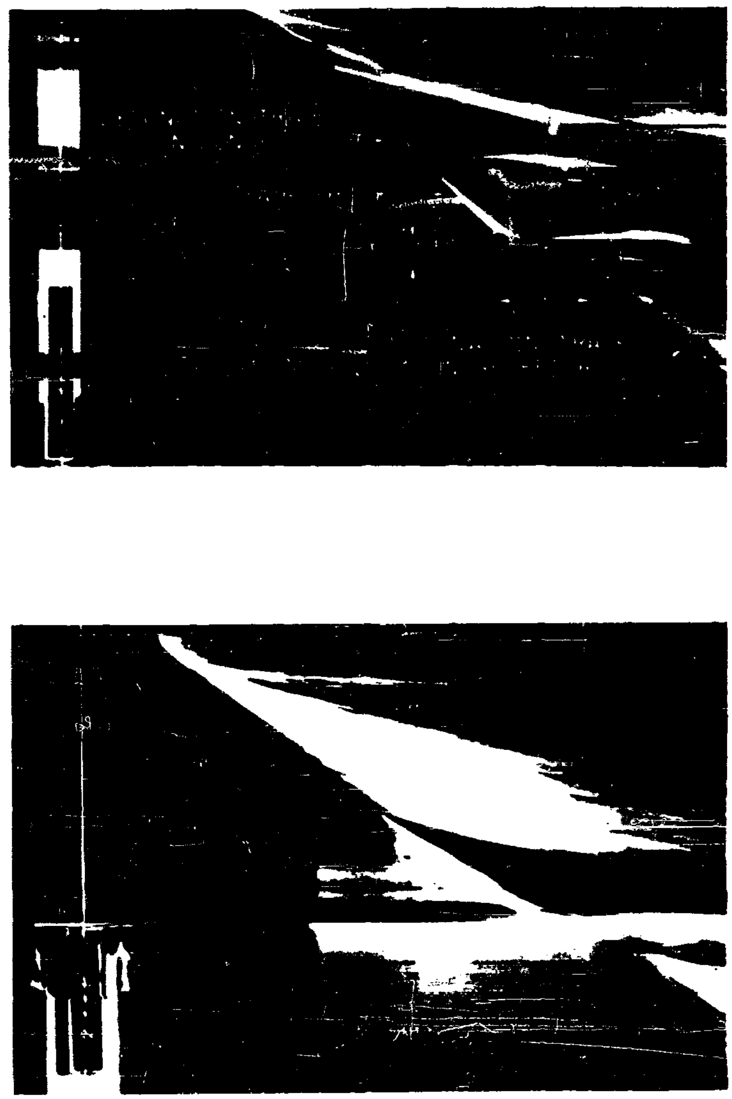

2- Typical Streak-Camera Records Showing Time and Distance "Delay" to Onset of High Order Detonation

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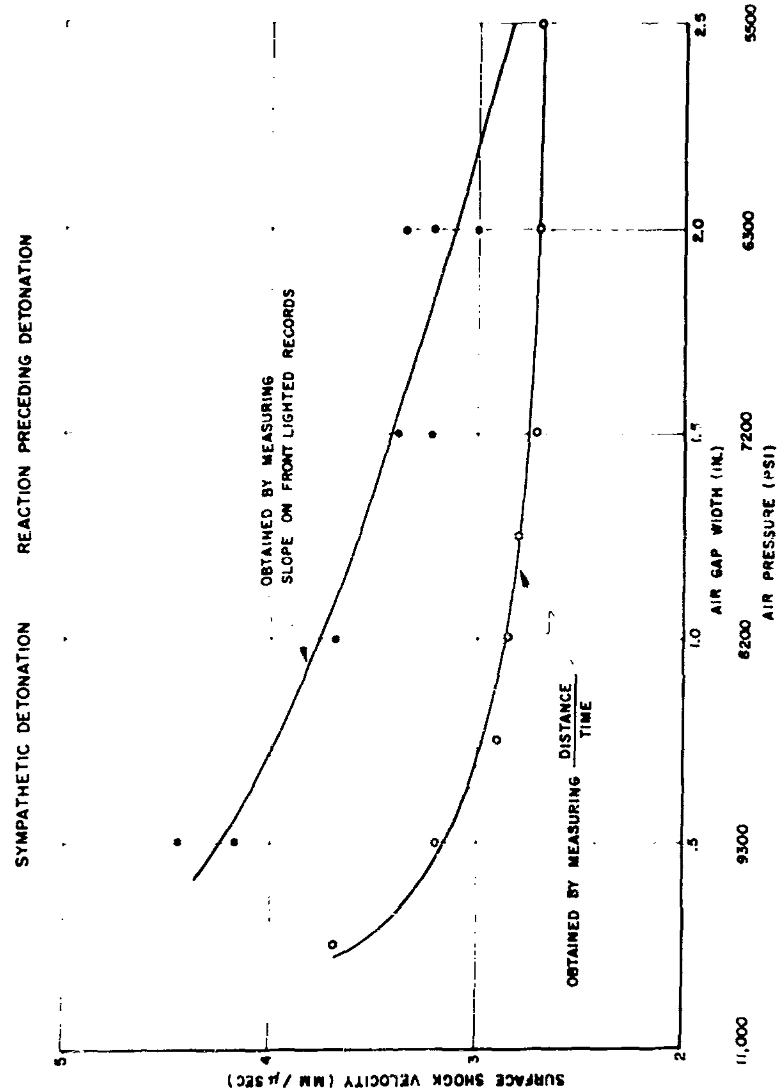

3- Pressure vs Velocity Measurements of Initial Shock in Receptor

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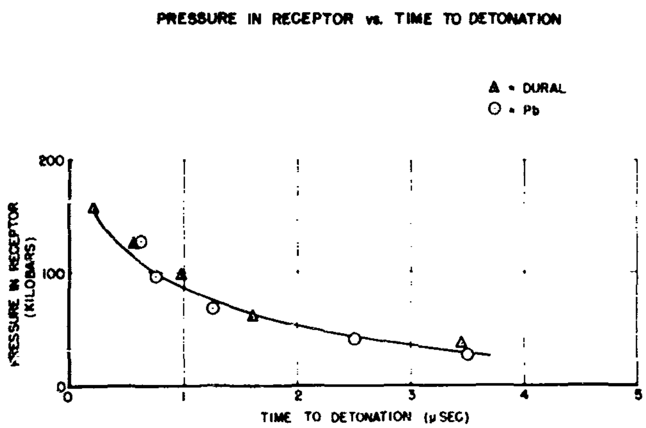

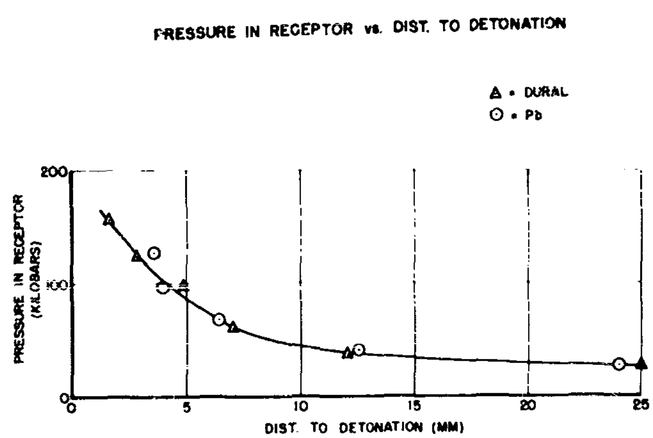

4- Time and Distance to High Order Detonation in Receptor as a Function of Pressure for Various Barrier Materials

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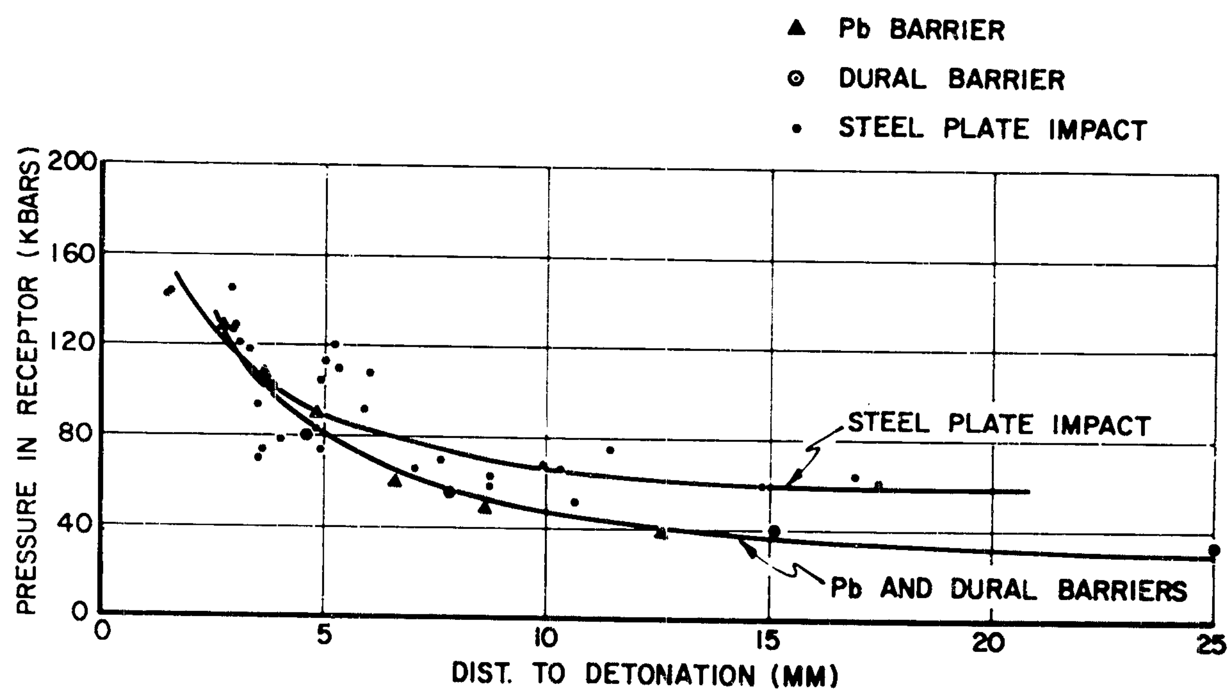
IMPACT INITIATION - PRESSURE RECEPTOR
VS.
DIST. TO DETONATION



5- Distance to Detonation vs Pressure in Receptor
(Summary for Barriers and Plate Impact)

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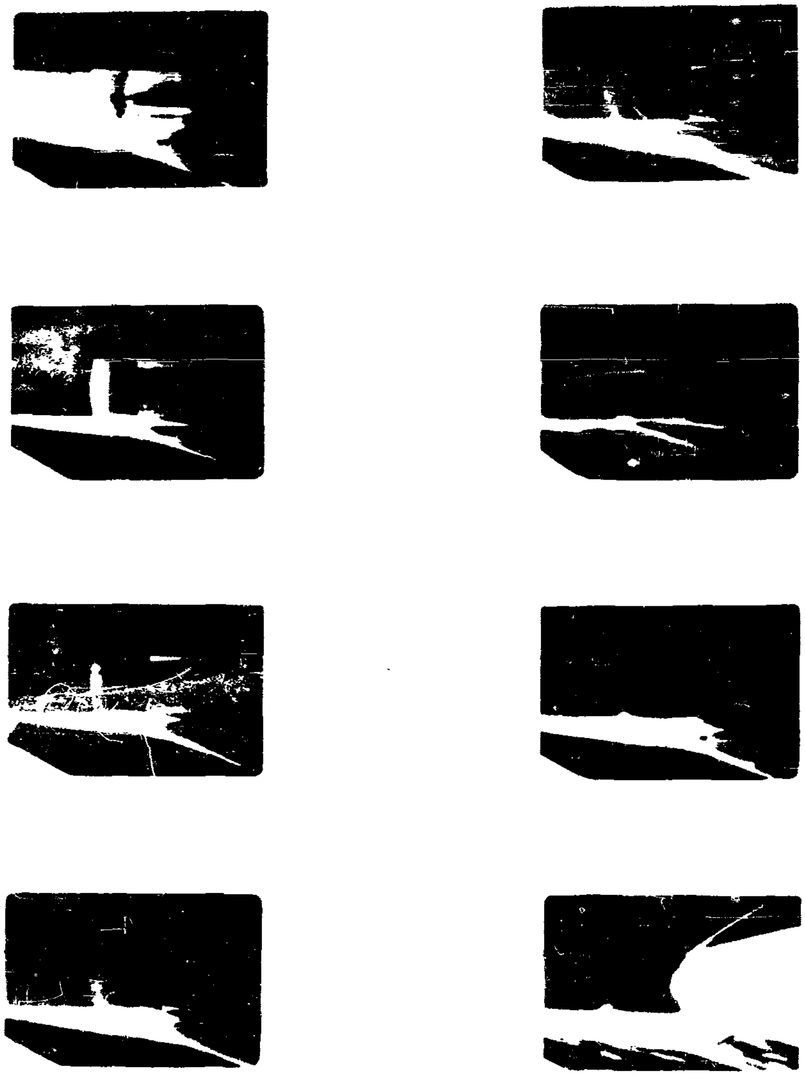

6- Series of Streak-Camera End View Emergence Records
Showing "Core" Reaction

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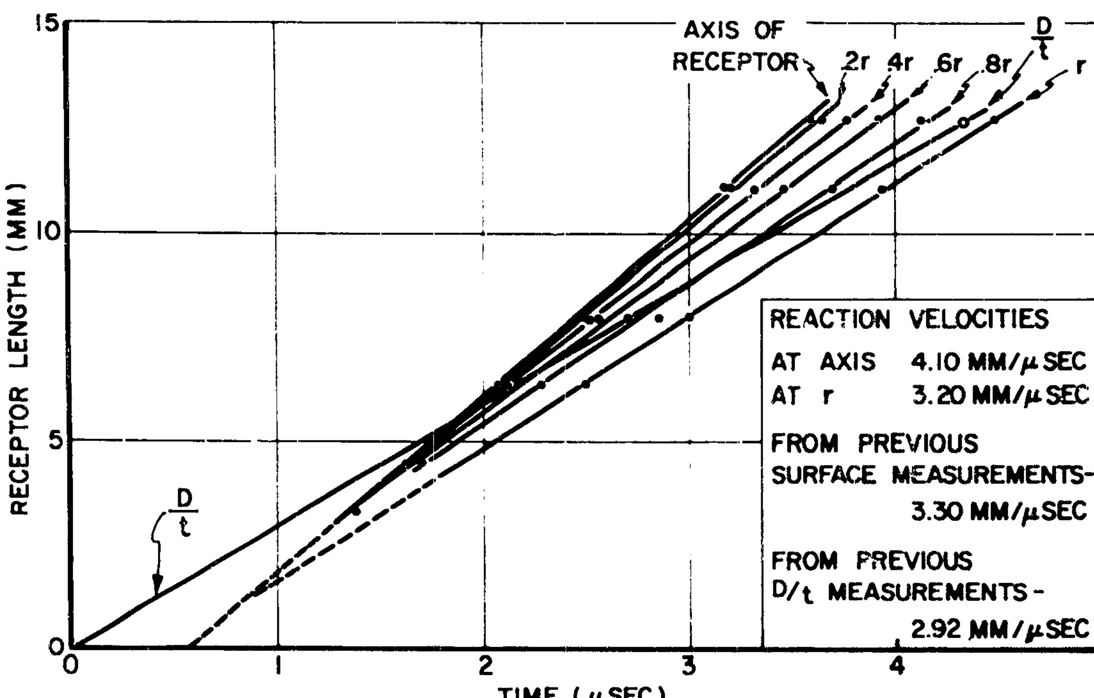
SYMPATHETIC INITIATION – 1.5" AIR GAP
SHOCK TRANSIT TIME IN RECEPTOR VS. RECEPTOR LENGTH
PLOTTED FOR DIFFERENT RADII AT REAR SURFACE OF RECEPTOR



7- Plot of Shock Velocity in Receptor as a Function of Distance from Axis of Charge at Fixed Pressure at Face of Receptor

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Mr. King: Are the shock interreaction and wave shaping mentioned synonymous in your view?

Mr. Sultanoff: When you have a shock interraction you have a change in the wave shape, always mock interraction. A shock is such that the interraction becomes a mock interraction, you form a stem, and what comes out then is a differently shaped wave. If you want to use the word wave shaping, this is one of the techniques we use for wave shaping, yes. But they're not synonymous really. There is a tremendous amplification, you can get up to 15 times the pressure, just take a very high pressure shock striking the wall, a reflective shock could be shown to be 15 times stronger than the initial impacting shock and these interractions have the same sort of amplification. The stem that comes out of this reaction is a higher velocity which shows immediately it must be a high pressure if its moving this same media.

Mr. Wenzel: ...I notice that you are using a cube with your charges, have you ever used cylinders?

Mr. Sultanoff: Yes, and the results were identical. The reason we use squibs is this. You used to study one above the other with a metal barrier between them with the detonation running parallel and this required the square configuration. Since we had all the molds up - you know what our hot melting plant is like - we just continued using the square sticks. But we have fired many dozen cylindrical sticks and the physical phenomena is identical.

Mr. Wenzel: Is there a minimum diameter for which your donor charge will not go into a detonation?

Mr. Sultanoff: Yes, there are tremendous scaling factors, especially when you start reaching the normal critical diameter of a charge that will normally support detonation started with a high order detonation and those problems become manifested exponentially. There is a tremendous scaling factor and we've had them playing around with but the number of shots you have to fire becomes astronomical but there is this scaling factor, yes.

Mr. Wenzel: Have you established this minimum diameter?

Mr. Sultanoff: I have some data actually written on scaling where you have a fixed donor to different size receptors and a fixed receptor to different size donors. One of the things, of course, is this business of retonation, as you get a larger and larger receptor, you start getting retonation because you have all this crushed up explosive that is still intact enough to support a detonation. The sensitivity

apparently goes up as the charge gets bigger from a certain critical diameter. After you reach a certain large diameter, it makes no difference, you have essentially infinite. Now I might mention, that pentolite the lower critical diameter of course is something on the order of 1/2". The large critical diameter which then becomes infinite and the data no longer changes, is about 2½". A 2½" acceptor will almost always detonate with the right pressure, but making it larger does not change the time-distance data at all. Of course when I say time-distance I'm giving you the distance to break out detonation at the core. We subtract the time it takes to propagate to the surface, otherwise the data is all off.

Mr. Wenzel: What is the length of the combustion zone vs the donor and the receptor?

Mr. Sultanoff: We're trying to determine this now with electrical probes in the system by measuring the amount of ionization and this is the only measure we have. The more ionization, the more reactive and we hope to be able to check back. We don't have any figures, but I would suspect that that zone can be the full length of a 6" stick in the case where you have a very low probability you may detonate 4" down the stick. So you have a constant changing chemical reaction that starts along with something along the reaction Hugoniot when the products are one thing - the things reacting are something else but you never end up along a high order condition so that you may have any number of chemical reactions and therefore this thing can be spread out the full length of this stick internally.

Mr. Henderson: In your explanation of the shock front initiation causing localized hot spots progressing to ignition and to detonation, does this particular explanation hold true for liquids as well as solids?

Mr. Sultanoff: Yes, I think we just had the answer here - hot spots, but what is the mechanism that generates the energy. The "hot spot" is some sort of transferred energy from the shock into the material that causes it to start to react.

FILM

ATLANTIC MISSILE RANGE LAUNCH ABORTS

by
Louis J. Ullian
Air Force Missile Test Center
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Mr. Nance: First comment I'd like to make is that the incident have been talking about is many times larger than the Polaris wl would account in part for the greater propellant, etc. Another that I'd like to make is that you were looking at pictures of t different types of destruct systems. The first destruct system a head-end mounted system that was designed to blow from the he end of the missile. I believe that those pictures that you s where the thing gets burned from both ends similar to the Polar burnings and then dropped and did some impact damage when it h the ground was that type of destruct system. The later one, I your System 2080, that had a linear shaped charge destruct sys that ran the length of the missile from the head to the aft en the Stage I motor was split completely open and that particula of destruct system was designed to fragment and to release a l... number of particles.

Mr. Ullian: The same thing is true of the Polaris, we've never done it to the degree that Minuteman has. The thing that I think is hard to explain is what caused these impact problems which we had on this one, what happened here.

Mr. Nance: I had another comment on that, you mentioned that the Stage II and III, in fact you showed a picture where a large piece of propellant from Stage II or III impacted with the sand and apparently burned. You said there was no detonation. Yet there was a crater there that appeared to be in excess of 15 ft. in dia.

Mr. Ullian: It was about 10 ft. in diameter and about 6 ft. deep maybe.

Mr. Nance: It wasn't a very big one but of course again there wasn't much propellant. I was wondering if there was any possibility that the propellant could have buried itself a considerable length, a lot of it remaining and splattering the propellant over a large area.

Mr. Ullian: I can tell you what some of our experts opinions of what ppened with that one first stage and I think it's something all of should start considering when we start thinking about hazard classication. That first stage impacted at a very high velocity, about 0 ft. per second, and when it hit the ground it evidently caused a ssive cracking in the propellant, the sand also acted as a confinent and we got some sort of reaction. Just what the reaction was, don't know, I don't think anybody knows. Certainly the damage that s done by that first stage was of greater magnitude than any other irst, second or third stage, whether class 9 or class 2 propellant, hat we have ever launched and had a failure with at the Cape.

nidentified: I think that certainly you have a very good point and ertainly I've said this myself that the fragmentations from these otors is -

r. Ullian: I'm not talking fragmentation, I'm talking overpressure, last damage too. This is something that I know of that has never been xperienced in a Class 2 motor before, this type of damage from impact. I've seen 40 ft. and 100 ft. drop tests and we just haven't gotten this type reaction.

Unidentified: Your velocities that you are talking about are not really too great a detonation, in fact we have impacted this particular propellant with high velocity fragments traveling 6,000 or 7,000 ft. per second and have not been able to induce detonation.

Mr. Ullian: I don't say it was detonation, I don't know what it was, but I do know it did major damage.

Mr. Walther: In certain instances I'm going to have to agree with the man from Thiokol, I think in some cases if we compare the destruction of the two systems we have two different types of destruct systems. If we compare the way the motors hit, you're comparing apples vs oranges. Undoubtedly there are some areas which must be clarified. However, in the fragmentation velocity and the number of fragments due to the type of destruct system, I think we'll find tomorrow when I show fragmentation films that our fragmentation data correlates very well as to the number and velocities of fragments and possibly as to density and I think as far as the dispersion patterns are concerned in order to indicate what the maximum hazard distance will be and what the density factors will be for specific distances are very realistic. I think you'll see some very interesting fragmentation patterns. The work group that Col. McCants and Russ Perkins are handling at the present time on fragmentation, I hope, will in the not too distant future have more answers about the fragmentation characteristics of solid motors and we'll know where we can go from there.

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DEMONSTRATION

on

STATIC ELECTRICITY

by
H. E. Poland
Bureau of Mines
Department of the Interior
Oakland, California

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DETONATION INITIATED BY HIGH PRESSURE GAS LOADING OF A SOLID EXPLOSIVE

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ABSTRACT: An important safety consideration is whether the accidental detonation of one ordnance item will induce detonation in adjacent ordnance. The present work is concerned with critical conditions for inducing detonation by high pressure gas loading of the explosive. Such a loading can result from the action of gaseous detonation products on ordnance located near an accidental detonation or from the confined burning of highly compacted explosives. Both situations are illustrated experimentally, and a one-dimensional numerical code has been used to show the characteristics of the critical gas loading.

It has been known for some time that the gas loading of a solid high explosive can effect its transition to detonation The shock sensitivity (gap or booster) test with an air medium is an example of this. Originally it was thought that conduction and convection from the hot gas and solid products of the donor explosive might have a large role in initiating the acceptor, but enough experiments have been made with the acceptor face insulated against hot gases and hot particles to show that this is not the case. Similarly, the shock transmitted from the donor to air and from air to the acceptor was once considered a dominant factor. It is easy to show that, in many cases where detonation occurs, such a transmitted shock is far below the required initiating pressure, e.g., Ref. (1), (2), (3). This leaves, as the most probable cause of the initiation, the pressure loading of the solid explosive by the gas products of the donor.

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That this is the major factor in such initiation was suggested to the writers some years ago by Dr. S. J. Jacobs of this Laboratory; it was subsequently suggested in the literature and one preliminary measurement of about 20 kbar was made on a Plexiglas receptor at one inch from 0.75 inch square x 3 inch long pentolite donor, Ref. (2), but no further work on gas loading has been reported.

There can be no doubt that high pressures are created by detonation product gases. Lutzky, Ref. (4), using Taylor parameters for a centrally initiated sphere of pentolite computed the pressure-time history on spherical walls at various distances from the charge. For a one pound sphere fired in a vacuum, the computed maximum wall pressure 4 cm from the surface of the charge is 22 kbar, in quite good agreement with the preliminary result of Ref. (2). The average pressure rate dp/dt in the range 10-20 kbar is about 4.5 kbar/μ sec.

At the writers' request, Lutzky carried out an analogous one-dimensional computation for the longitudinal geometry of the NOL gap test, Ref. (3), (5): a 5.08 cm long tetryl donor (ρ_0 =1.51) and the receptor wall at 13.97 cm. Both the geometry and the computation results are shown in Fig. 1. In the absence of any lateral rarefaction, an extraordinarily flat-topped pulse is obtained; its pressure of about 50 kbars would be exerted for about 8 μ sec at a fixed wall 13.97 cm (5.5 in.) from the surface of the tetryl donor; and the rate of pressure rise is 13 kbar/μ sec. Because the gap test has two-dimensional effects, the pressure obtained, its duration, and its rate of rise would all be expected to be lower than corresponding values of Fig. 1.

Experimentally, the standardized NOL gap test geometry for gas loading is a 5.08 cm diameter x 5.08 cm length tetryl donor followed by a 13.97 cm long steel tube and the witness. When a 3/8 inch thick steel plate is used as witness, the tetryl detonation products, after traveling down

the steel tube, load and damage the plate by bending and bulging it, Ref. (3). If in place of the steel plate, a second 5.5 inch long tube filled with cast Composition B is used as a witness, the Comp B detonates. Comp B (RDX/TNT/Wax, 60/40/1) has an initiating pressure in this geometry of about 21 kbar, Ref. (5). When cast TNT (initiating pressure of about 37 kbar)is used as an explosive witness instead of Comp B, it fails to detonate as a result of the gas loading from the standard tetryl donor.

These results confirm Lutzky's computed value and indicate that the experimental geometry (two dimensional) produces a loading pressure of between 21 and 37 kbar at the witness location. Gaseous detonation products can therefore create, in short build-up times, pressures of the order of magnitude of initiating pressures for high explosives, they can also cause high explosives to undergo a transition to detonation.

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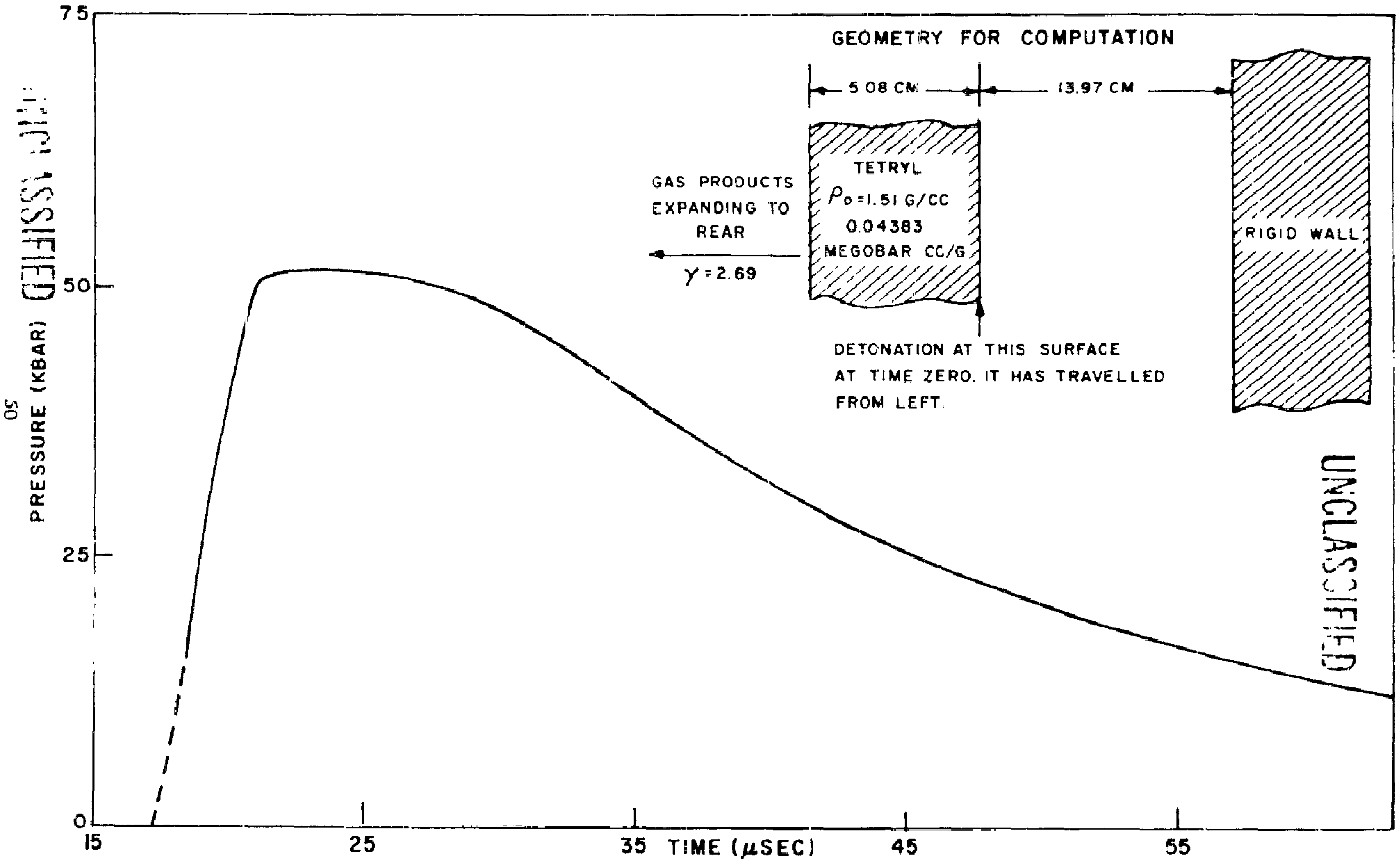

FIG. 1 GAS LOADING AT WALL 13.97 CM FROM STANDARD GAP TEST DONOR

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So far, only gas loading of an acceptor explosive by an explosive donor has been considered. Another method of obtaining gas loading is by the confined burning of the explosive itself. Fairly recently work has been done on hot wire initiation of highly confined cast explosives, Ref. (6). It was found that the pressure build-up in the region of the hot wire is very rapid after a pressure of 1 kbar has been reached, and could be approximated by a pressure function exponential in time. Its average pressure rate in the 10-20 kbar region is 0.9 kbar/μsec or greater. Maček and Zovko, Ref. (7), used a one-dimensional code to show that an exponential p-t loading to 30 kbar, and there maintained, at the boundary of a solid explosive could cause its transition to detonation at an interior point.

The objective of the present work is to demonstrate that donor product loading and confined burning of cast explosives effect detonation by the same mechanism, i.e., gas loading, by investigating realistic pressure-time loadings and reliefs for the confined burning.

USE OF THE 1-D CODE FOR SHOCK INITIATION

The code available for this work was a one-dimensional hydrodynamic code into which Arrhenius type reaction had been incorporated. It was constructed by Enig and Metcalf, Ref. (8), who used it to reproduce the trend of shock initiation pressure vs. specific heterogeneous explosive found experimentally in the shock sensitivity test performed with a rapidly decaying shock from the donor, Ref. (9). However, they did not demonstrate that the same treatment reproduces the experimentally established behavior under shock of a single heterogeneous explosive. This will be done now so that subsequent computations for gas loading may be restricted to a single explosive.

The most frequently observed sensitivity phenomena of shocked solid explosives are: the existence of a critical initiating pressure, break-out of detonation downstream from the shocked boundary, and a consistent decrease of both the run-distance* and delay time** to steady-state detonation with increased amplitude of the applied shock pressure.

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* Distance from shocked surface to plane in which steady-state detonation is first established.

** Total time from entry of shock into explosive until moment steady-state detonation begins.

A typical trend for run-distance vs pressure in cyclotol 65/35 when approximately flat-topped shocks are used, is given by Campbell, Davis, Ramsay and Travis, Ref (10). In the more common test geometries, both lateral and longitudinal rarefactions occur. Cosner's data, Ref. (11), (12), show the trends obtained in such a case; they are displayed in Fig. 2 and are qualitatively the same as those obtained with the flat-topped shocks.

Table 1 contains the results, computed for cyclotol 75/25 with the use of the 1-D code, Ref. (8). The same values of the parameters for the equation of state and of the Arrhenius equation as those used by Enig and Metcalf, Ref (9), have been used here, but the shocks are flat-topped instead of rapidly decaying. The artificial linear viscosity was kept at the value of 10^5 poise used in the earlier work.

TABLE 1

Numerical Results for Effect of Shock Amplitude on Run Distance and Delay Time for Cyclotol 75/25

Shock Loading[a] Particle Velocity mm/μsec	Shock Loading[a] Pressure kbar	Run Distance X_s mm	Total Delay Time τ μsec
0.50	30.6	Failed	Failed
0.55	34.5	194	67.79
0.56	35.3	51.65	16.82
0.57	36.1	39.93	12.77
0.58	37.0	31.46	10.45
0.65	43.0	9.971[b]	4.100[b]
0.70	47.0	4.242[b]	2.544[b]
0.80	56.5	<2.31[b]	<1.384[b]

Parameters used in code from Ref. (9). Viscosity is 10^5 poise and charge length, 27.94 cm; 100 mesh points used in computation. Cyclotol 75/25 is RDX/TNT, 75/25.

a Flat-topped, no rarefaction.
b Mesh size too coarse to permit accurate values.

The data of Table 1 are plotted in Fig. 3 which shows that the computed results reproduce the trends found experimentally. That the code also finds a critical initiation

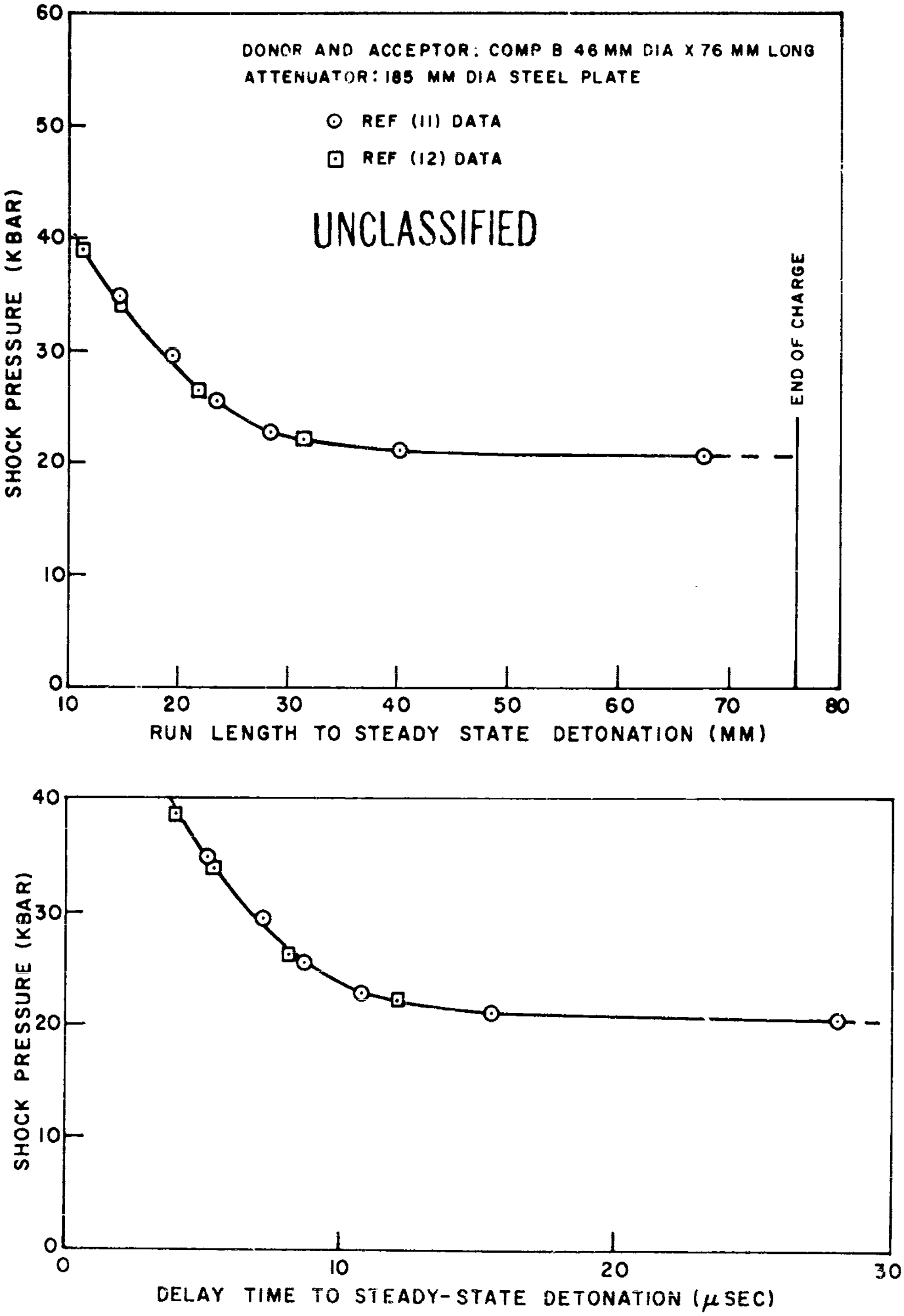

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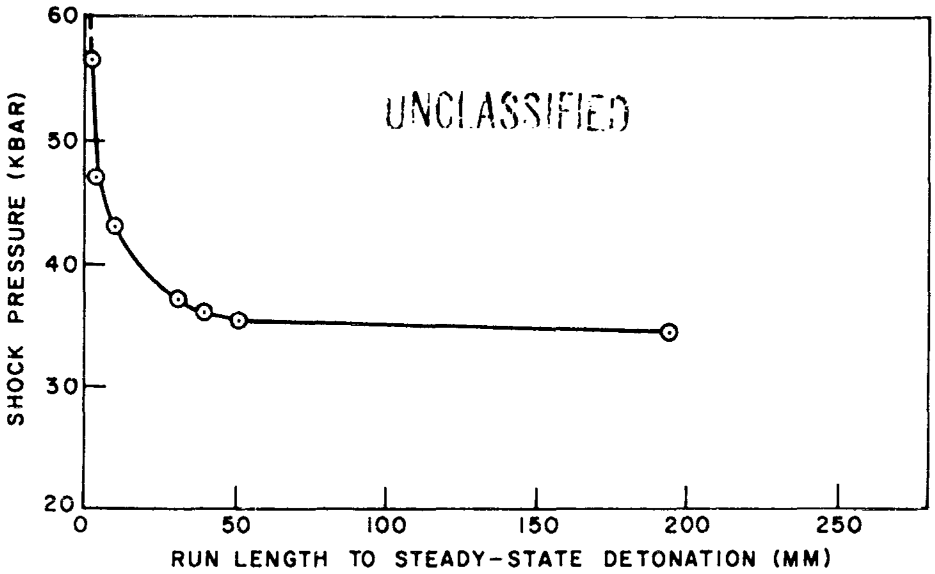
FIG. 2 VARIATION OF RUN LENGTH AND DELAY TIME WITH SHOCK PRESSURE

ONE DIMENSIONAL COMPUTATIONS FOR CYCLOTOL 75/25



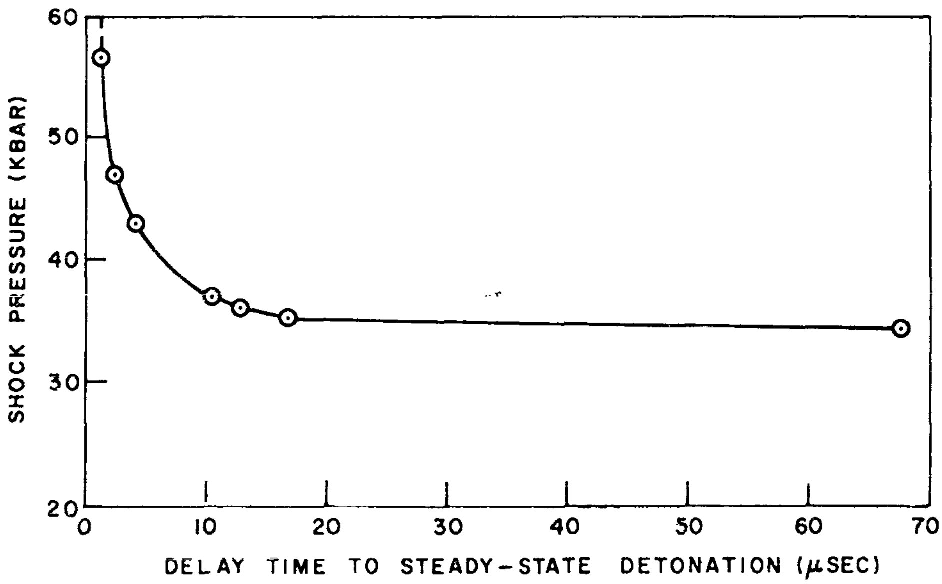


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FIG. 3 VARIATION OF RUN LENGTH AND DELAY TIME WITH SHOCK PRESSURE: THEORETICAL RESULTS FOR FLAT-TOPPED SHOCKS

pressure* and an interior break-out of detonation has been established in the earlier work, Ref. (9). The program therefore reproduces the qualitative aspects of shock initiation of heterogeneous solid explosives and can now be used to examine the effects of gas loading.

The linear viscosity function in this code acts implicitly as a mechanism for dissipation of energy. The way in which it acts is complex; it is sufficient to note here that its value determines the numerical stability of the problem and does not affect the computed initiation pressure. Its value does, however, affect the computed values of the run-length and delay time as is illustrated by the data of Table 2. A decrease in the viscosity factor results in moving the location of the detonation nearer the surface or, at loadings nearer critical, in changing the response from a failure to a detonation. As shown in Table 2, a decrease of 50% can be made before numerical instability first appears; the corresponding decreases in X_s and τ are about 25%.

TABLE 2

Effect of Varying Viscosity on Computed Values

Viscosity Poise	Run Length X_s, mm	Delay Time τ, μsec
10×10^4	39.93	12.77
8×10^4	34.16	11.21
7×10^4	31.37	10.56
6×10^4	31.03	9.942
5×10^4 [a]	29.44[b]	9.365[b]

Material: Cyclotol 75/25
Loading: Flat-topped shock of 36.1 kbar

a Limit of numerical stability reached at this viscosity.
b Values less accurate than those above because of coarse mesh size; 100 mesh points used. Charge length 27.94 cm.

* The critical pressure of cyclotol 75/25 given in Table 1 is somewhat more precisely determined than that in the previous work, i.e., 34.5 kbar rather than 35.

The mathematical form chosen for the pressure loading is

$$P = P_o \exp(kt) \qquad (1)$$

and corresponds to the pressure-time behavior observed at pressures of about 3 4 kbar in the confined burning of the deflagration to detonation transition (DDT) experiments, Ref. (6). The exponential function offers a convenient way to obtain the high rates, dp/dt, observed experimentally; it is the high rates at the high pressures rather than the exact form of the p-t function that determine transition to detonation. The value of $3.5 \times 10^4 sec^{-1}$ for k was used in exploratory computations; this value is about half the minimum value measured in DDT shots in which detonation occurred, Ref. (6).

The numerical experiments consisted of loading the face of a cylinder of cyclotol 75/25. For the k chosen, it was found that the loading of Eqn. (1) caused detonation of the charge downstream from the loaded boundary, provided (a) the maximum pressure reached at the boundary was equal to or greater than the shock initiation pressure of the explosive (found to be 35 kbar in previous computations, Ref. (9)), and (b) the pressure is not relieved too rapidly. For example, if the loading of Eqn. (1) is taken to only 30 kbar, even if it is maintained at 30 kbar for 10 μsec, detonation is not effected. Similarly even if the loading of Eqn. (1) is taken to 35 kbar, but instantly relieved, no detonation occurs.

Parallel studies in the transition from deflagration to detonation have shown that the initiating pressure for pentolite in the DDT geometry can probably be achieved in the burning area before the tube ruptures, Ref. (6). Fig. 4 shows a typical pressure-time curve, Ref. (6), for a pentolite shot in which transition to detonation occurred; it is bounded by two exponentials used in the computations of the present work. The confining tube ruptured after a plastic deformation of about 3 mm. on the radius. For the shot and time-scale of Fig. 4, a plastic deformation of 2 mm. on the radius had been reached at the end of 42 μsec. Extrapolation of the pressure-time curve gives a pressure of about 26 kbar at 42 μsec. The initiating pressure for pentolite in this geometry is about 19 kbar.

Results of typical computations with maximum amplitude equal to the initiating pressure are given in Table 3. They demonstrate that the more rapid the loading, the more rapid the relief may be and still result in detonation. In interpreting these results, it must be kept in mind that the 1-D

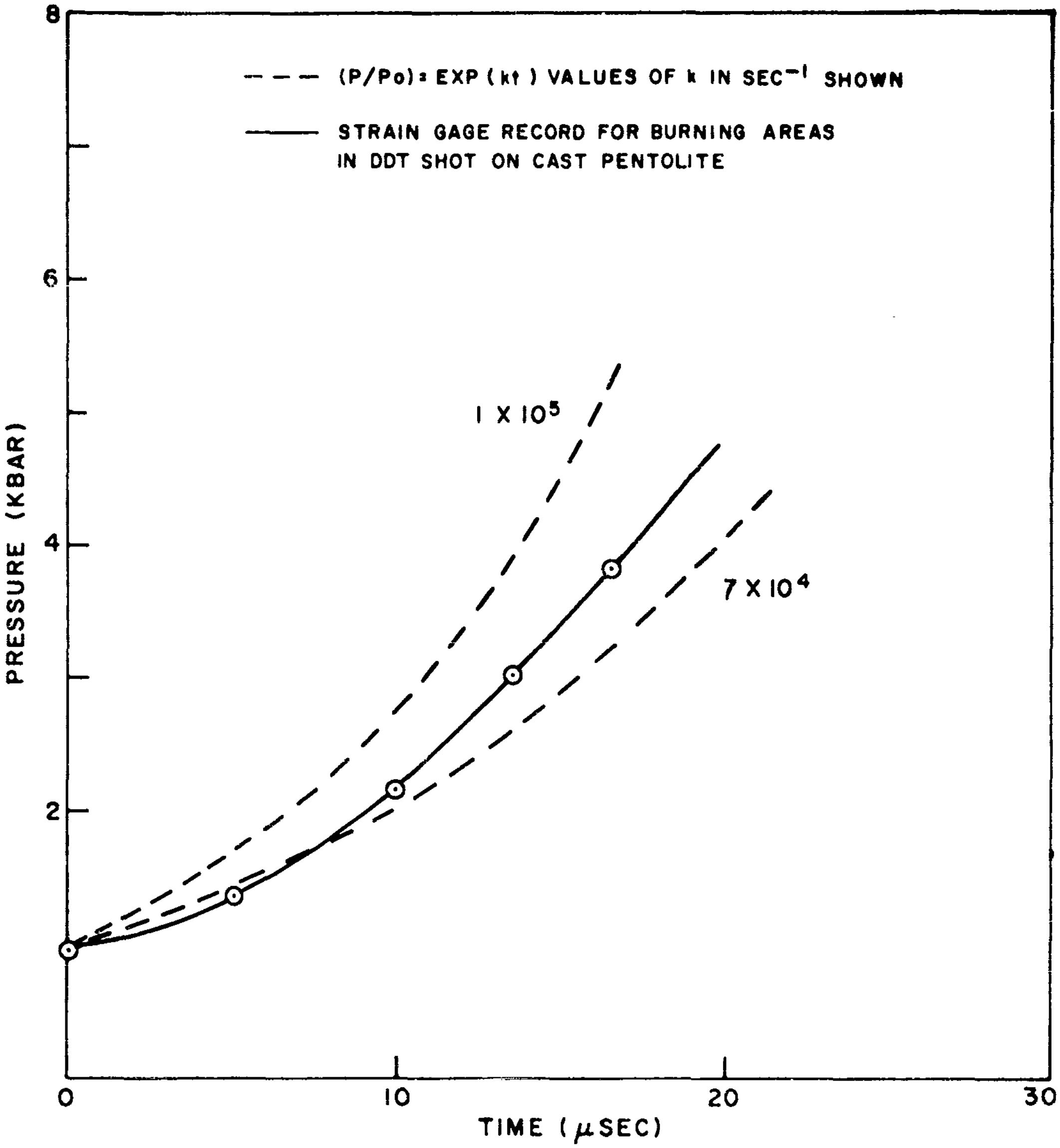

FIG. 4 COMPARISON OF TWO EXPONENTIAL CURVES WITH EXPERIMENTAL PRESSURE TIME CURVE IN A DDT SHOT

code used describes the chemical reaction by a first order Arrhenius mechanism. The explosion of any unit of the material depends on that unit's being heated to some temperature and being kept at that temperature for the necessary corresponding induction time. The pressure loading compresses and thereby heats the explosive. Some of the energy supplied by the loading will be dissipated, and it is the net result of energy put in minus the energy lost that determines whether detonation occurs. Energy loss, reflected as lowering of the temperature, will occur because of decompression i.e., the unloading wave and, in some cases, rarefaction from the cylinder face opposite to that loaded. Rarefaction from the downstream face of the charge may prevent the development of detonation within the charge length although the same loading would lead to detonation in longer charges. This is a factor present chiefly for exponential loading; it occurs in shock loading only if the shock front is badly smeared out by the numerical treatment.

In Table 4, the exponential loading to 35 kbar is kept constant at $k = 7 \times 10^4 sec^{-1}$; the unloading is varied from the most rapid permitting detonation ($K = 1.85 \times 10^5 sec^{-1}$) down to practically zero ($K = 3 \times 10^3 sec^{-1}$). In addition to the existence of a critical unloading rate, the results show that the slower the unloading is, the shorter the run distance and the delay time become.

Table 5 contains computations showing the trend to be expected when unloading is kept constant (here, at zero) and the rate of loading is varied. This series was run slightly above the critical pressure and at a viscosity of 6×10^4 to save machine time. The trend is increasing run-length with increasing rate of loading. Of course the limit of the exponential loading is a shock loading, and as the rate is increased, the exponential results converge on those from the analogous shock. The numerical results are not exactly the same because of two factors: inaccuracies introduced by coarseness of the mesh and those arising from location of the first pressure point about 1.35 mm. outside the first cell.

In agreement with the trend of Table 5, comparison of the last value of Table 4 with the third of Table 1 emphasizes the result that at the critical pressure, exponential loading produces a shorter run distance than shock-loading although the total time to detonation will generally be greater for the exponential loading because of the interval it requires to reach the critical pressure. This result too must be interpreted in terms of the chemical reaction built into the code: that the pre-working of the exponential load, by raising the temperature of the explosive, assists the transition to detonation.

TABLE 3

Computed Effects of Various Loadings on Cyclotol 75/25

Loading[a] $P=P_0 \exp(kt)$	Unloading[a] $P=35 \exp(-Kt)$	Run Distance[b]
k, sec^{-1}	K, sec^{-1}	mm
3.5×10^4	2.0×10^4	F[c]
3.5×10^4	1.0×10^4	69
6.0×10^4	1.6×10^5	F
6.0×10^4	1.5×10^5	75

Linear viscosity 10^5 poise; 40 and 50 mesh points used respectively for loadings of 3.5 and 6×10^4.

a P in kbar, t in sec. Initiating pressure for cyclotol 75/25 is 35 kbar, Ref. (9).

b Distance of point of initial detonation from loaded boundary. All charges were 13.97 cm. long.

c F: Charge failed to detonate within the 13.97 cm. length.

TABLE 4

Effect of Relief of Boundary Loading on Initiation of Cyclotol 75/25

Loading[a] $P=P_0 \exp(kt)$	Unloading[a] $P=35 \exp(-Kt)$	Run Distance[b]	Delay Time[c]
k, sec^{-1}	K, sec^{-1}	mm	μsec
7×10^4	1.90×10^5	F[d]	--
7×10^4	1.85×10^5	128	27
7×10^4	1.80×10^5	103	21
7×10^4	1.00×10^5	46	8
7×10^4	3.00×10^3	32	5

Linear viscosity 10^5 poise; 100 mesh points used.

a P in kbar, t in sec. initiating pressure for cyclotol 75/25 is 35 kbar, Ref. (9).
b Distance of point of initial detonation from loaded boundary. All charges were 27.94 cm. long.
c Exclusive of 52μsec rise time from 1 to 35 kbar.
d F: Charge failed to detonate within the 27.94 cm. length.

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TABLE 5

Effect of Varying Loading Rate on
Initiation of Cyclotol 75/25

Loading Exponential[a] k, sec^{-1}	Delay Times (sec) τ_1[b]	τ_2[c]	Run Length min
7×10^4	51.23	3.94	25.5
1×10^6	3.586	11.04	34.3
5×10^6	0.717	17.04	52.7

a No unloading. Maximum pressure of 36.1 kbar reached and then maintained. Linear viscosity of 6×10^4 poise; charge length of 27.94 cm; and 100 mesh points used.
b Time for pressure to reach 36.1 kbar from initial value of 1.
c Time from attaining 36.1 kbar pressure to time of detonation.

CONCLUSIONS

The following conclusions can be drawn from the results of the numerical computations:

1. The numerical treatment of shock initiation of heterogeneous explosives devised by Enig and Metcalf, Ref. (9), reproduces the trends found experimentally.

2. Gas loading of the boundary of a heterogeneous explosive can cause detonation downstream from the loaded boundary provided:

a. the maximum pressure reached is equal to or greater than the shock initiation pressure under the usual solid barrier conditions,

b. the pressure-time curve for the loading is sufficiently steep (k of $3.5 \times 10^4 sec^{-1}$ or greater in this code), and

c. the relief of the loading is not too rapid.

The p-t curves, though steep, may be several orders of magnitude less steep than a shock front (See Table 3). Thus a steep, but not necessarily a discontinuous, pressure front

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can create reacting areas capable of reinforcing the front of the disturbance. In the critical situation just capable of producing detonation, material at the detonation location will stay at the same pressure and temperature for the required induction time after which the pressure and temperature will change instantaneously to the detonation values. In the more common case of a net energy well above critical, the material will exhibit first a slowly rising temperature followed by an accelerated growth to the steady state detonation conditions.

3. Both the air gap test ((P/ t)≈4.5 to 13 kbar/μsec) and the DDT experiments ((P/ t) ≈ 1 kbar/μsec) are experimental examples of the gas loading mechanism indicated by the theoretical results.

4. The slower the pressure rise of the loading curve, the slower must be its release if detonation is to occur. This must be interpreted in terms of the net effect of the dissipations. It cannot mean an inverse relation between total impulse and effectiveness in causing detonation.

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THE EFFECTS OF ACCEPTOR-DONOR CONFIGURATION AND DIMENSIONS ON CARD GAP AND CRITICAL DIAMETER

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ABSTRACT

Explosives and propellant shock sensitivity test results are significantly influenced by specific donor and acceptor parameters. Parameters such as density, confinement, length to diameter ratio, and composition have been investigated by others. Initial propellant detonability investigations at Allegany Ballistics Laboratory (ABL) have confirmed previous results and provided more specific data concerning parameter influence on critical diameter and card gap results. These investigations have also shown the care required to select test parameters if valid data are to be obtained, and emphasized the precautions necessary to interpret test results.

On the basis of these investigations, the following have been concluded:

(1) Two methods, the conical acceptor test and critical-diameter prediction from card gap values obtained with different donor diameters, appear to be the only techniques available for establishing small ($\leq$ 0.50 inch) critical diameters with precision.

(2) The critical diameter test which employs both a constant diameter acceptor and a varying diameter donor is feasible for establishing approximate values.

(3) Valid card gap results are obtained only if the acceptor diameter is at least twice the critical diameter and the "effective" donor length is at least three times its diameter.

(4) To compare card gap values for different propellants directly, test results must be obtained with a single donor diameter, or an extrapolation made using test results obtained with two different diameters. If a single donor diameter is used, it should equal the largest acceptor diameter, particularly when acceptor diameters are at the 2:1 acceptor diameter to critical-diameter ratio.

(5) The relationship between card gap values obtained with cylindrical and conical donors for different propellant formulations is not linear. Therefore, conversion from cylindrical donor to conical donor card gap values may not be possible unless tests are performed with at least two different donor diameters for each donor configuration.

(6) Card gap values are not affected by changes in acceptor diameter, provided the acceptor diameter is in excess of the 2:1 acceptor diameter to critical diameter ratio; however, card gap values increase linearly with donor diameter within the test limits employed.

INTRODUCTION

In the field of explosive and propellant sensitivity, it is common knowledge that card gap and critical diameter test results are significantly influenced by donor and acceptor parameters. Factors influencing test results such as confinement, temperature, density, and the acceptor length to diameter ratio have been investigated by the Naval Ordnance Laboratory (NOL), Rohm & Haas, the Bureau of Mines, and the Research and Development Establishment in Great Britain.[1,2,3,4,5,6] Previous work by NOL and Rohm & Haas has established the effect of acceptor length to diameter ratio on shock sensitivity results[2,4] and indicated the effect of donor diameter and donor length to diameter ratio on test results. At least one group (Rohm & Haas) determined that an acceptor diameter to critical ratio of 3:1[7] is required to obtain valid results. However, these tests were performed with various donor length to diameter ratios, most of which were less than 3:1 which indicated a lower ratio may be sufficient. The confinement effect on card gap has been studied at NOL.[1,2] Investigators at NOL have also developed and described a critical-diameter-determination method.

Previously, donors with different shapes as well as different densities and explosive materials have been used in card gap testing. NOL has done extensive work to establish a relationship among tetryl, pentolite, and Composition-B.[6,9,10]

During the course of propellant detonability investigations at ABL, specific data have been accumulated concerning the influence of donor and acceptor configuration and dimensions on critical diameter and card gap results. The results confirm past work by others and provide specific details on test-parameter control. Such results may serve to introduce some of the precautions which are necessary to conduct programs and interpret test results. The areas considered in this paper are (1) propellant critical diameter test methods; (2) the influence on card gap value of acceptor diameter to critical diameter ratio; (3) the effect of donor configuration and length to diameter ratio on card gap values; and (4) card gap values as a function of donor and acceptor diameter.

TESTS AND TECHNIQUES

The 50-grain plastic-coated Primacord® (lead witness plate system) was employed to detect detonation[11] in all tests. This system was selected in preference to the metal witness plate technique because Primacord® can be initiated by a pressure pulse as low as 5 kilobars and at shock velocities in excess of 1500 m/sec.[12] The 5-kilobar value was obtained by card gap tests[12] using the NOL calibration curve for tetryl. Such a system provides a clearer differentiation between low order reaction and detonation. The arrangement of the Primacord® in relation to the donor and acceptor and the length of the acceptor were selected to minimize the probability of Primacord® initiation by shock from the donor or fragments.

All propellant card gap and critical diameter tests presented were conducted with unconfirmed acceptors to avoid the influence of confinement on the effective charge diameter.

Propellant critical diameter tests were conducted with bare cylindrical acceptors (minimum length to diameter ratio of 6:1) and Composition C-4 donors (minimum length to diameter ratio of 3:1); Engineers Special electric blasting caps were used as initiators. Reported critical diameters are those at which three failures are obtained with detonation being observed at the next larger (generally 0.1 inch) test diameter.

Card gap tests were performed with cylindrical acceptors (minimum length to diameter ratio of 6:1) using Composition C-4 donors and Engineers Special electric blasting caps as initiators. The attenuators which comprised the gap between donor and acceptor were Lucite® and cellulose acetate cards. Gaps were altered in 0.05-inch intervals; therefore, reported values are in the range (± 0.00-inch to + 0.04-inch) of the "true" gap.

The ABL card gap test is designed to establish the minimum gap which will prevent detonation rather than the 50% probability point. The reported value is that gap thickness at which three failures are obtained with detonation occurring at least once at the next lower (by 0.05-inch) thickness.

DISCUSSION

Critical Diameter

Two similar critical-diameter-determination methods use either a (1) conical or (2) stepped cylindrical acceptor which is base-initiated.[6,13] (See Figure 1.) The diameter at which ionization fails, measured by a continuous wire, is recorded as the critical diameter. One disadvantage of this method is "overshooting" which results from the energy transmitted forward along the acceptor. To avoid "overshooting" and difficult sample machining and to use simpler detection methods, ABL has employed cylindrical samples with Primacord® (lead witness plate detection systems). The methods considered were (3) varying acceptor with the donor diameter equal to acceptor, which is the more common technique, (4) constant donor-varying acceptor diameter, (5) constant acceptor-varying donor diameter, and (6) predicting critical diameter from card gap values.

Method (3) has been used several years at ABL and is considered the standard. The validity of results obtained by the third method is questionable because of the difference in energy produced by different donor diameters. This effect is further compounded when the diameter of the donor material approaches its critical diameter. Such is the case for unconfined Composition C-4 which cannot be relied on to propagate a detonation below one-half of an inch.[12] Method (4) overcomes the objectionable feature of using different diameter donors, but requires machining of small-diameter acceptors. The same question arises in regard to method (5). However, an advantage of this method is acceptors do not have to be machined to many different diameters, and thus

far it is the most economical technique to estimate critical diameter. One double-base propellant has been tested in an attempt to develop method (5). Table I shows a comparison of results obtained by methods (3) and (5). Based on these results which are in agreement, method (5) would permit critical-diameter approximations. Although further work is required using different compositions and acceptor configurations, method (5) appears to provide a relatively fast and inexpensive means of determining propellant critical diameters of 0.5-inch or above using Composition C-4 as a donor.

An interesting result of the study is the possibility of critical-diameter prediction from card gap results. Tests were conducted to show the donor-diameter effect on card gap value. Three typical curves are shown in Figure 2. Since the card gap values decrease linearly with donor diameter and critical diameter is defined as the dimension which will not propagate a detonation, it is reasonable to assume the zero card gap point on this curve is the critical diameter. Critical diameters were calculated by least squares for all propellants tested in this phase of the study. The values obtained for the three propellants in Figure 2 are presented in Table II. The agreement between predicted values and experimental critical diameters, methods (3) and (4), is good. The experimental values being higher than the predicted values were anticipated considering the reasons given previously. Although no comparison has been made for propellants with critical diameters greater than 0.70-inch, it seems reasonable to assume that agreement will be good for larger diameters.

When the requirement for more energetic propellants is considered, it is expected that they will become more shock sensitive and exhibit smaller critical diameters. The most reasonable and valid techniques of establishing small (< 0.5-inch) critical diameters would appear to be the card gap versus donor-diameter-prediction method and possibly the stepped or conical acceptor methods.

Card Gap

Since it is well known that acceptor and donor dimensions influence shock sensitivity test results, it is obvious that certain criteria are required for the selection of test parameters.

Acceptor Diameter to Critical Diameter Ratio: Obviously, the selection of diameters below the acceptor and/or donor critical diameter would be meaningless. Thus, one necessity is to determine how much larger than its critical diameter the acceptor must be for propagation of a steady state detonation and provision of valid card gap data. Preliminary work in this phase, with a composite-modified double-base propellant (CRU), indicates the ratio of acceptor diameter to critical diameter should be in the neighborhood of 2:1 (see Figure 3), which suggests that the Rohm & Haas minimum value of 3:1 may have resulted from using donor lengths less than the normal 3:1 ratio or an effect of composition. One value of establishing the lower limit is to reduce material costs and blast effects for acceptors with large critical diameters; for example, a propellant with a critical diameter of 4 inches would be 8 inches by 32 inches using the

2:1 ratio and 12 inches by 48 inches using the 3:1 ratio. Testing too close to the critical diameter will, as seen in Figure 3, result in lower card gap values which emphasizes establishing accurate critical diameters before testing to obtain card gap values. The practice of using some standard card gap size such as the NOL card gap test without knowledge of the critical diameter could produce data which will result in an erroneous hazard classification based on the Phase II card gap tests.

Conical vs. Cylindrical Donors: Tests have been conducted to establish the relationship between Composition C-4 conical and cylindrical donors. Cone-shaped donors have been previously employed primarily to reduce blast effects, noise, and costs. The curves in Figure 4 show the relationships for a double-base (ARP) and a composite-modified double-base (DMM) propellant. The lower card gaps produced by a conical donor indicate donor diameter must be constant over a length at least three times as large as the donor diameter. When the cylindrical donor work is used as the criterion, the shock wave in the conical donor apparently cannot achieve optimum shape since the diameter is continually changing. One possible explanation for the intersection of the curves at 1.0 inch (see Figure 4) is that the shock wave in the conical donor has achieved a radius of curvature equal to that of the shock wave in the cylindrical donor. The difference in relationships for different propellants shows that it may not be possible to use a simple equation for conversion of data from conical to cylindrical donors. This difference may result from a combination of donor shape, test interval, and "effective" donor length.

Donor Length to Diameter Ratio: Another factor which influences card gap is the donor length to diameter ratio. Tests performed with a double-base (ARP) propellant (see Figure 5) indicate a minimum ratio of 3:1 is required for valid results. It should be noted that knowledge of the minimum ratio is desirable not only for valid results but also for reduction of noise level, damage to test facilities and, cost of test materials. Possible explanations for this minimum ratio are (1) the shock wave must achieve a steady state reaction and (2) the shock wave must achieve its maximum radius of curvature. During this phase of work it was found that card gap values at a length to diameter ratio of 3:1 were slightly lower than expected for 1- and 2-inch diameter donors (see Figure 5). This low value may be attributed to the 0.05-inch test interval or, more likely, to the depth the initiator is inserted into the donor. This depth, nominally 1/2-inch - 1-inch, should be considered when preparing donors for testing. Tests were conducted on the same double-base composition (ARP) with an added donor length to compensate for the insert depth of the detonator. The results given in Table III show that the over-all donor length to diameter ratio is approximately 1 inch greater than 3:1. Thus, all references to "effective" donor length to diameter ratio indicate over-all donor dimensions of 3:1 plus 1 inch in length.

Varying Acceptor and Donor Diameters: Results of tests on a composite-modified double-base propellant (CRU) (see Figure 6) show that a change in acceptor diameter for a given donor, provided the acceptor is sufficiently large in relation to the critical diameter, has no effect on card gap. However, a change in donor diameter significantly affects the results (see Figure 7); for example, card gap value increases linearly with donor diameter. This effect of donor diameter on card gap value reflects the difference in donor-energy incident to the sample and should not be interpreted as showing a change in the propellant shock sensitivity.

The existence of these effects points out the care which must be exercised in selecting card gap test parameters, particularly in establishing the donor diameter and the relationship between donor and acceptor diameter. This is most evident if card-gap values are to be compared when the propellants exhibit different critical diameters. Results of work presented earlier show that since a 2:1 acceptor to critical diameter ratio is required, the acceptor diameters will differ. Therefore, if a valid, direct comparison of card gap values is desired, it is necessary to (1) use a single donor whose diameter equals the largest acceptor diameter required to exceed the 2:1 minimum acceptor to critical diameter ratio, or (2) test each propellant with a minimum of two different donor diameters. Conversely, if it is necessary to compare reported card gap values, particularly if they originate at difference sources, the donor diameter used in each test among other parameters must be known. When donor diameters differ for several card gap tests, the reported attenuator thicknesses must not be compared. However, it should be possible to compare results if card gap values are converted to pressures required for initiation of each donor diameter, provided pressure curves versus inches gap for each donor diameter and donor material are available.

Card gap tests performed on propellants of widely varying compositions show a difference in slopes as a function of donor diameter (see Figure 8). Since the slope varies from one propellant to another, neither critical diameter nor card gap can be predicted from one composition to another.

The discussion of the linear effect of donor diameter should only be construed to be true within the test limits. As the acceptor and/or donor diameter decreases, approaching the propellant or donor material critical diameter, the gap value should decrease. For very large diameter donors, it is conceivable that the portion of the shock front striking the acceptor could be essentially planar resulting in constant card gap values for further increases in donor diameter. This condition would be particularly true when the planar dimension exceeds the propellant minimum acceptor diameter to critical diameter ratio.

CONCLUSIONS

Based on the results obtained in the investigation thus far, the following conclusions have been reached:

(1) Determination of critical diameter by the constant acceptor-varying donor diameter method appears feasible for approximate results.

(2) Prediction of accurate critical diameters for a propellant from card gaps is possible provided values are obtained for at least two different donor diameters.

(3) The proper ratio (presently appears to be 2:1 or greater) of acceptor diameter to critical diameter must be used to obtain valid card gap results.

(4) The relationship between card gap values obtained with cylindrical and conical donors for different propellants is not well defined. Therefore, it may not be possible to use a simple equation to convert from one card gap value to another.

(5) For valid critical diameter and card gap results the "effective" donor length to diameter ratio should be at least 3:1.

(6) Direct comparison of card gap values necessitate that for different propellants a constant diameter donor be used or an extrapolation be made using results of two different donor diameters. If a single diameter donor is used, it should equal that of the largest diameter acceptor, particularly when acceptor diameters are at the minimum 2:1 acceptor diameter to critical diameter ratio.

(7) Card gap values are not affected by changes in acceptor diameter, provided the acceptor diameter is in excess of the 2:1 acceptor diameter to critical diameter ratio; however, card gap values increase linearly with increasing donor diameter within the test limits employed.

In summary, a number of factors are known to influence critical diameter and card gap values and emphasize the care which must be exercized in the selection of test parameters if valid data are to be obtained (see Table IV).

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GLOSSARY

Acceptor	Test sample receiving externally applied explosive shock produced by the donor charge.
Card Gap	Attenuator thickness required to prevent detonation of an unconfined test specimen.
Composite-Modified Double-Base (CMDB)	Solid propellant containing nitroglycerin or a highly nitrated plasticizer, nitrocellulose, AP and/or HMX solid oxidizer and metal fuel.
Composition C-4	Explosive donor material consisting of the following: RDX-91%, motor oil-1.6%, polyisobutylene-2.1%, and di-(2 ethylhexyl) sebacate-5.3%.
Composition B	Explosive booster material consisting of 60% pentaerythritoltetranitrate and 40% trinitrotoluene.
Critical Diameter	Diameter above which detonation of an unconfined test specimen can occur.
Donor	High explosive charge used to initiate the test sample (acceptor).
Double-Base (DB)	Solid propellant containing nitroglycerin or some other plasticizer and nitrocellulose as the principle ingredients.
Lucite ®	E. I. duPont de Nemours & Co., Inc., trademark for transparent, thermoplastic, synthetic resins made by the polymerization of acrylic derivatives.
Pentolite	Explosive booster material consisting of a 50/50 mixture of pentaerythritoltetranitrate and trinitrotoluene.
Primacord®	Ensign-Bickford Company trademark for a flexible cord with a central core containing PETN (pentaerythritoltetranitrate).
Tetryl	Trinitrophenylmethylnitramine - standard explosive booster material.

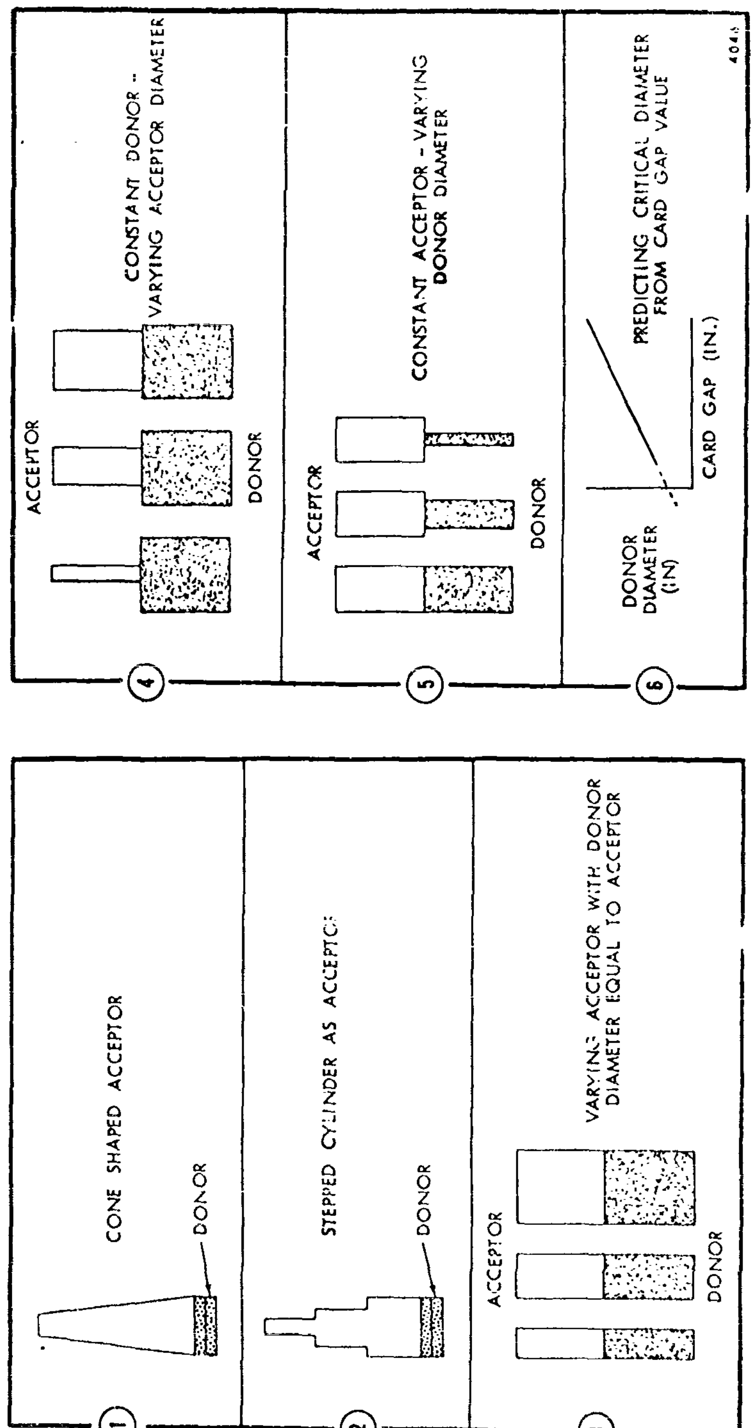

FIGURE 1
Methods of Determining Critical Diameter

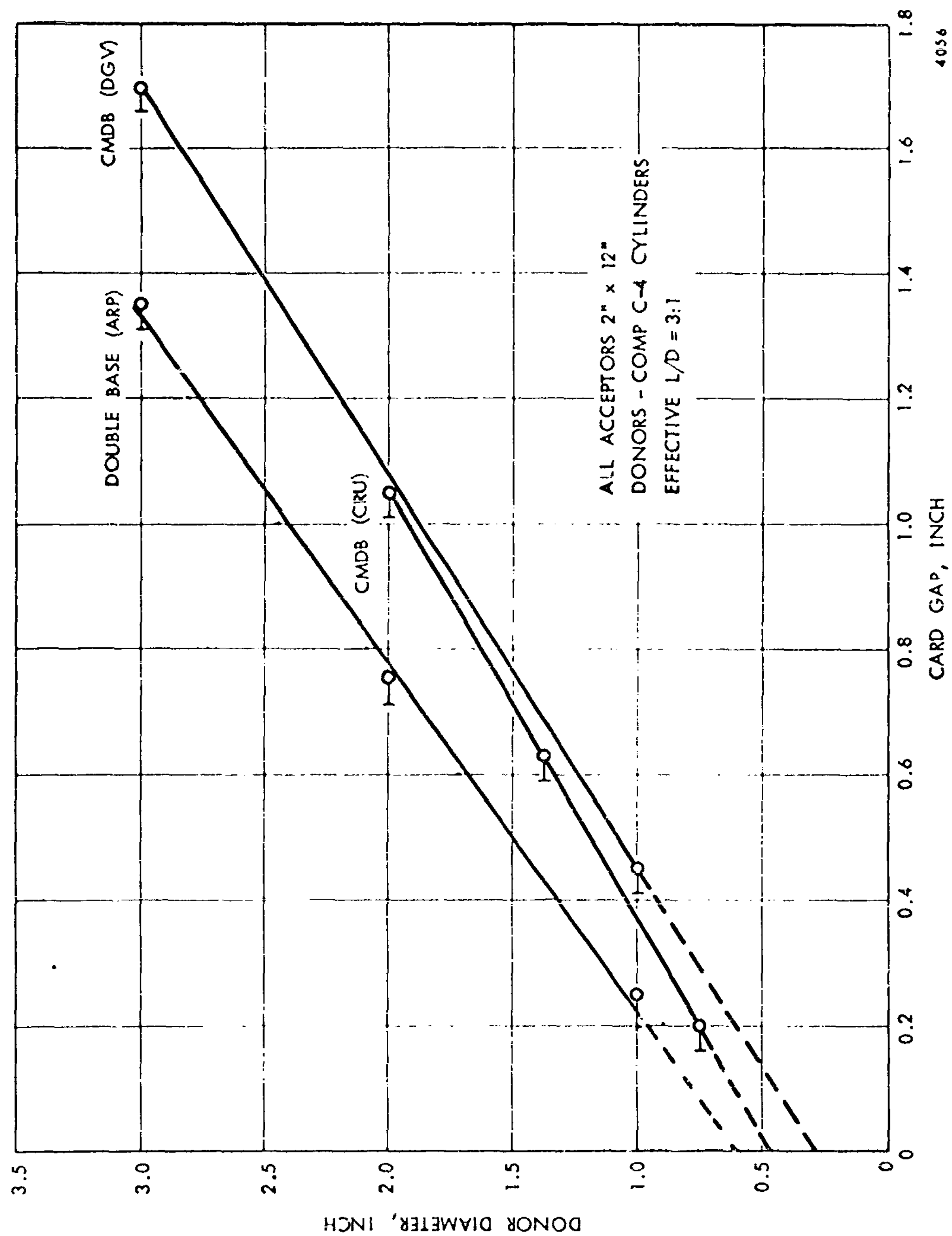

FIGURE 2
Card Gap Value vs. Donor Diameter

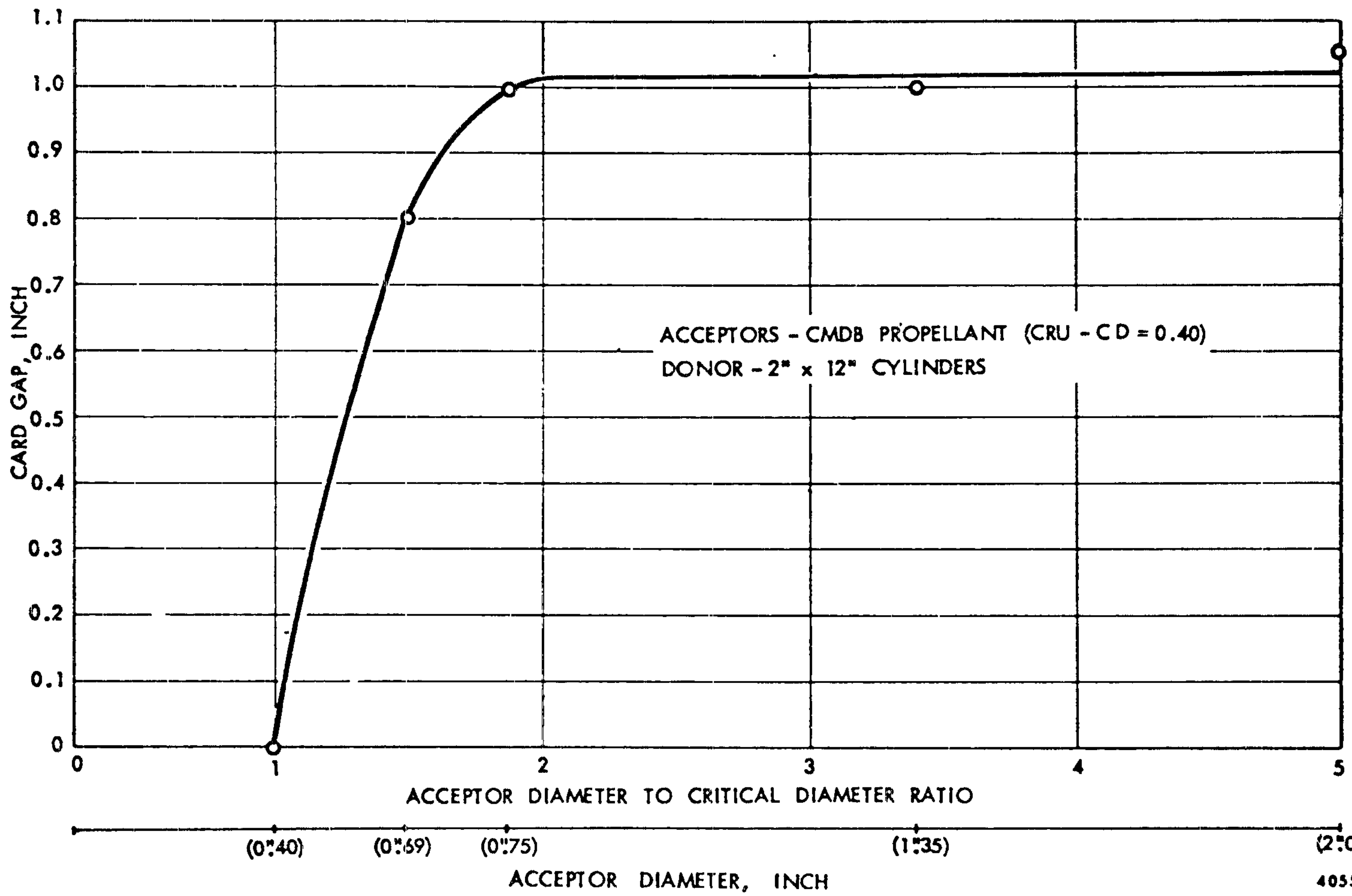

FIGURE 3
The Influence of Acceptor Diameter to Critical Diameter Ratio on Card Gap Value

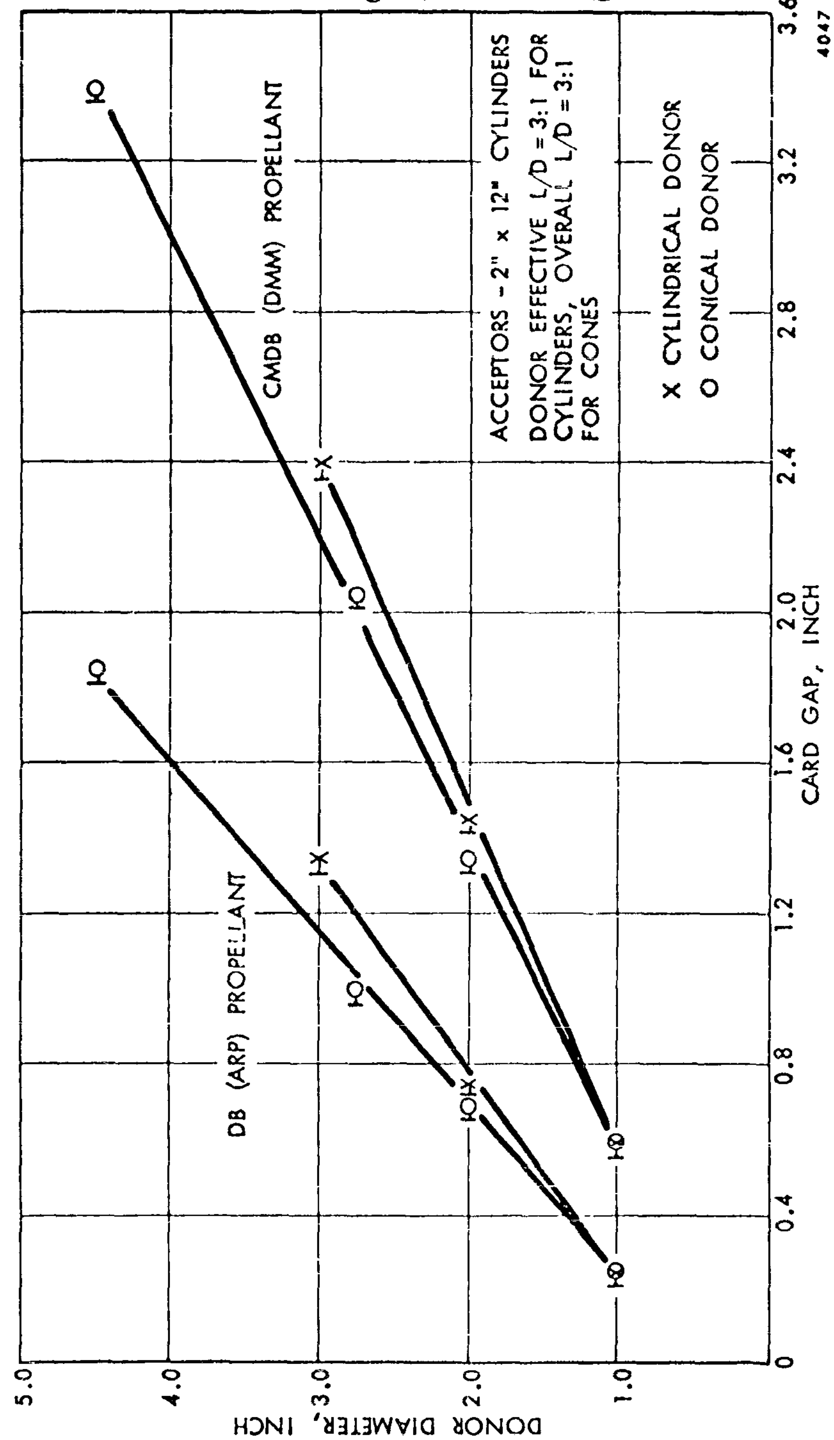

FIGURE 4
Card Gap Values with Cylindrical and Conical Donors

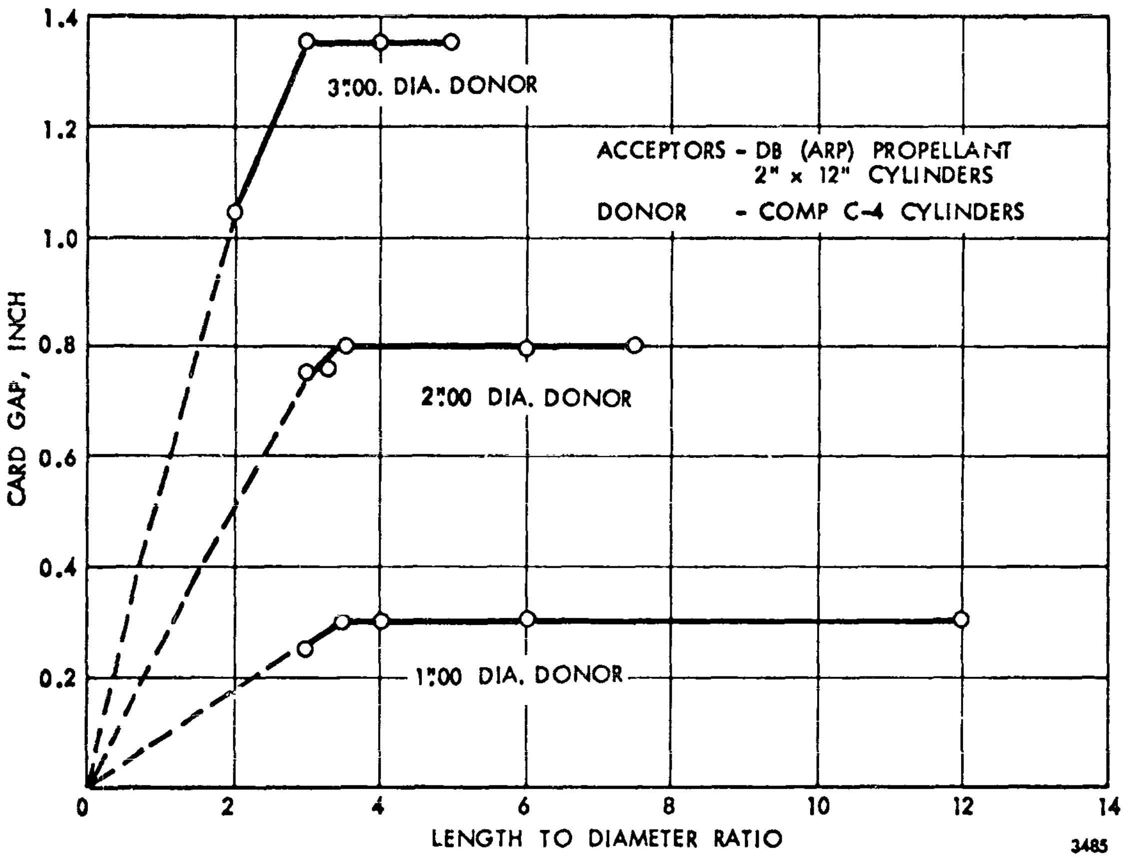

FIGURE 5
The Effect of Donor Length to Diameter Ratio on Shock Sensitivity

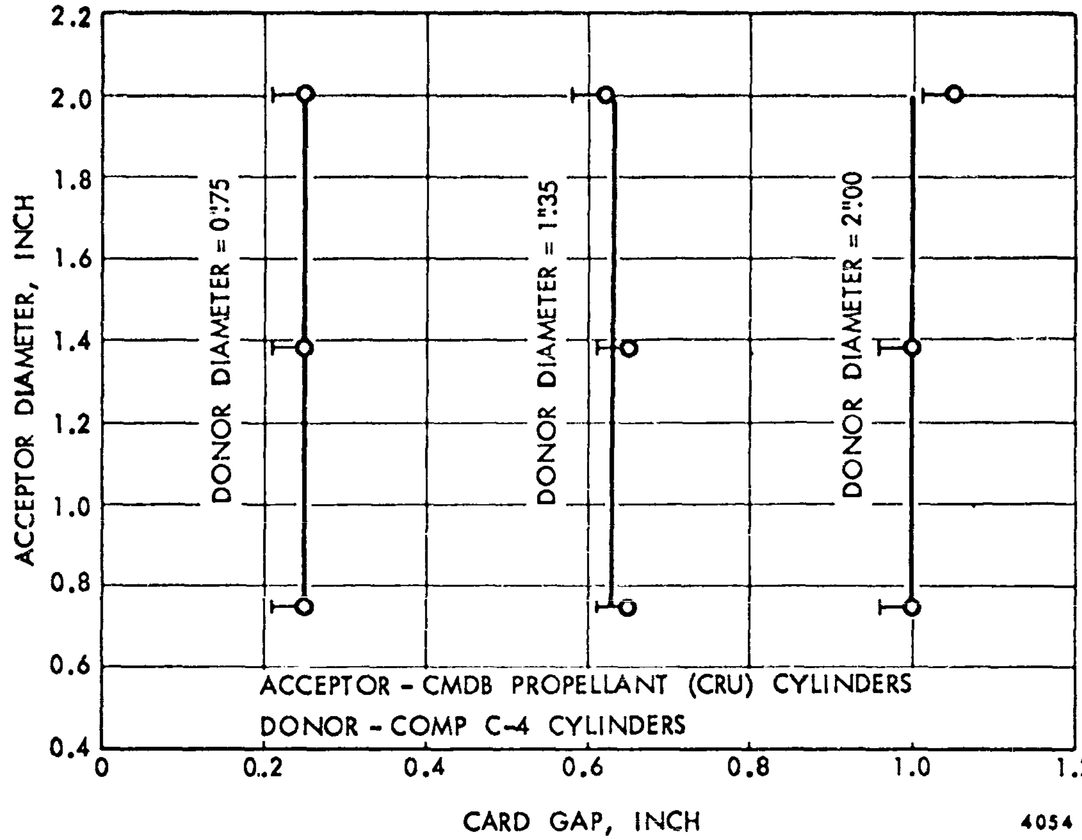

FIGURE 6
Acceptor Diameter Influence on Card Gap Value

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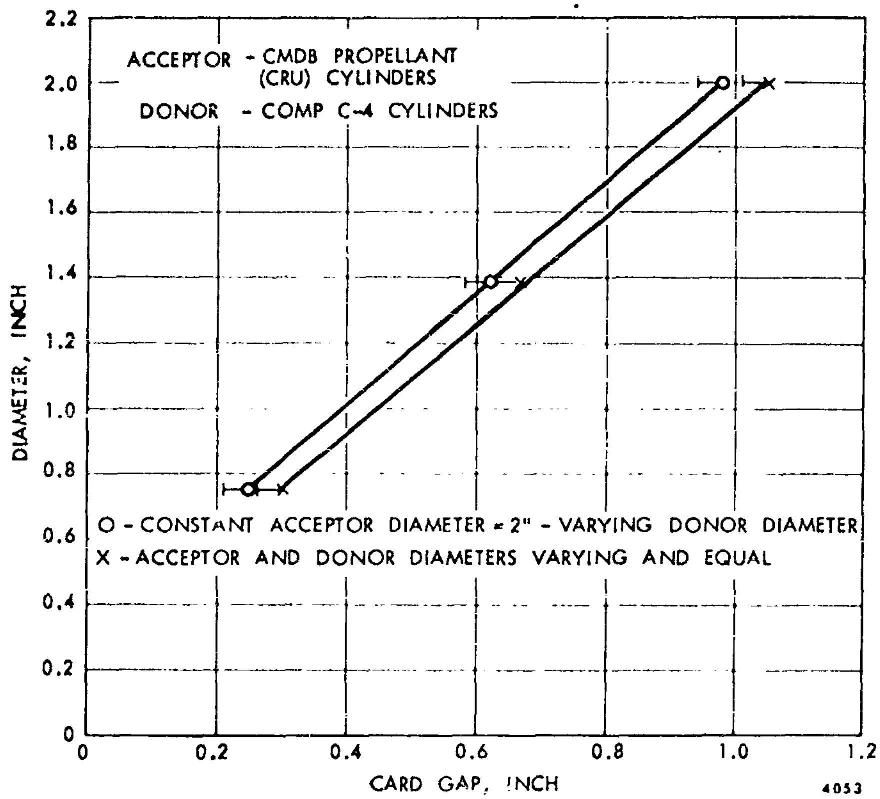

FIGURE 7
Effect of Donor and Acceptor Diameter on Card Gap Value

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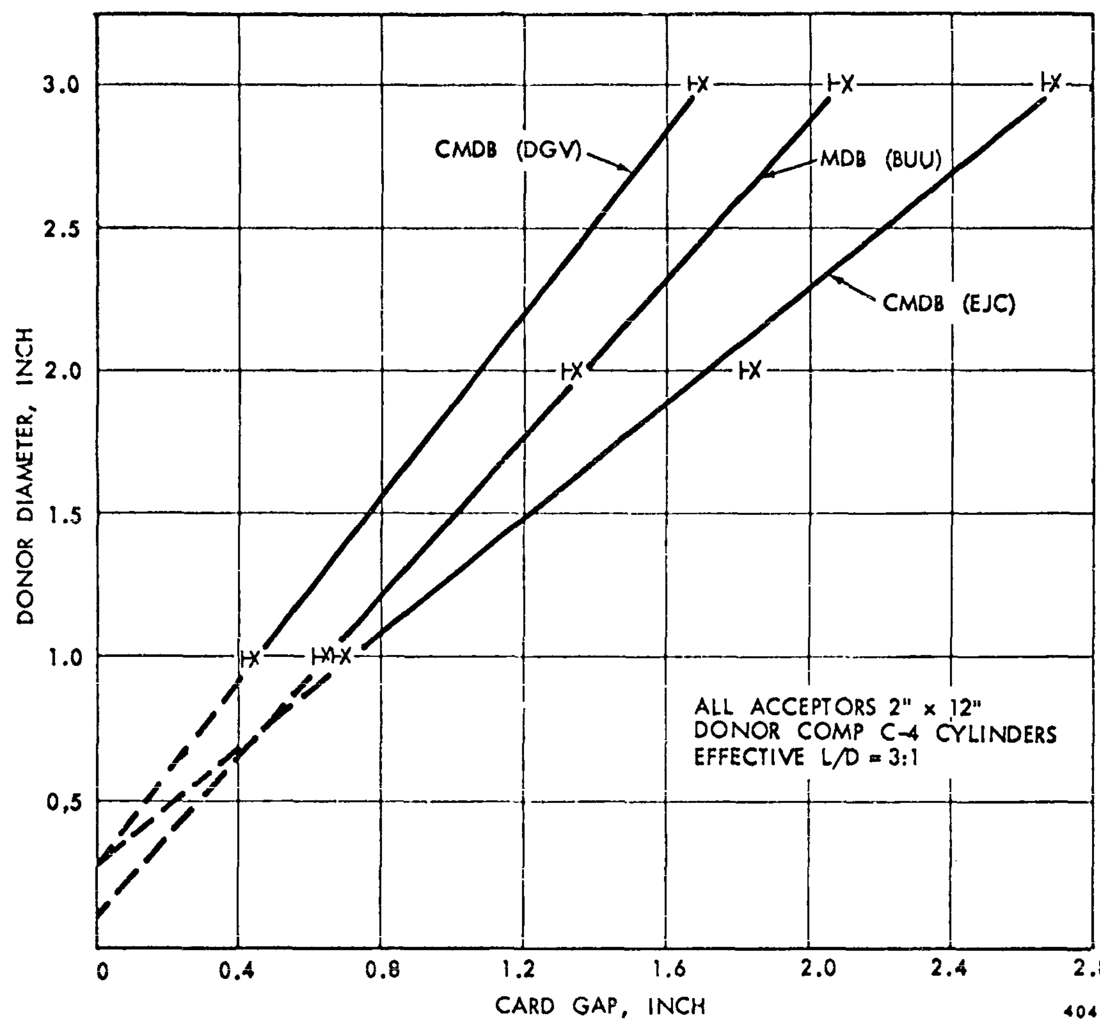

FIGURE 8
Card Gap Values for Different Propellants as a Function of Donor Diameter

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TABLE I

Determination of Propellant Critical Diameter by Different Methods

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METHOD 3 VARYING AND EQUAL ACCEPTOR AND DONOR DIAMETER				METHOD 5 CONSTANT ACCEPTOR - VARYING DONOR DIAMETER			
ACCEPTOR	DONOR	REACTION	C. D.	ACCEPTOR	DONOR	REACTION	C. D.
0".75 x 12"	0".75 x 12"	DET.	< 0".75	0".75 x 12"	0".75 x 12"	DET.	< 0".75
0".50 x 12"	0".50 x 12"	NO DET.	≥ 0".50	0".75 x 12"	0".50 x 12"	NO DET.	≥ 0".50

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TABLE II

Comparison of Experimental and Predicted Critical Diameter

PROPELLANT	EXPERIMENTAL METHOD 3		EXPERIMENTAL METHOD 4		PREDICTED BY METHOD 6	
DOUBLE BASE (ARP)	$\gtrsim$ 0."50	< 0."75	$\gtrsim$ 0."60	< 0."70	$\gtrsim$ 0."57	< 0."64
CMDB (CRU)		< 0."50	$\gtrsim$ 0."40	< 0."50	$\gtrsim$ 0."43	< 0."49
CMDB (DGV)	$\gtrsim$ 0."38	< 0."63	$\gtrsim$ 0."40	< 0."50	$\gtrsim$ 0."28	< 0."34

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TABLE III

Effective Donor Length to Diameter Ratio

SAMPLE	DONOR DIMENSIONS (IN.)	CARD GAP (IN.)*
DOUBLE BASE	1.0 x 3.0	0.25
PROPELLANT (ARP)	1.0 x 3.5	0.30
	1.0 x 4.0	0.30
	1.0 x 12.0	0.30
	2.0 x 6.0	0.75
	2.0 x 6.5	0.75
	2.0 x 7.0	0.80
	2.0 x 12.0	0.80

* INITIATOR INSERTED INTO DONOR 1/2"

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TABLE IV

Factors Influencing Critical Diameter and Card Gap Values

DONOR	ACCEPTOR
1. COMPOSITION	1. LENGTH TO DIAMETER RATIO
2. DENSITY	2. ACCEPTOR DIAMETER TO CRITICAL DIAMETER RATIO
3. SHAPE	3. CONFINEMENT
4. DIAMETER	4. TEMPERATURE
5. LENGTH TO DIAMETER RATIO	5. DENSITY

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Dr. Price: I think if you want to measure critical diameter by means of a gap test and you follow the definition of critical diameter you must use the same explosive as both a donor and an acceptor. The British made quite a discussion of this in a summary report after WW I. But diameter will be that diameter at which you just fill our explosive tube and propagate the reaction. Therefore, any interruption or zero gap will occur at critical diameter if you have your donor and acceptor of the same material. You'll vary from it on this method depending on how different the donor and acceptor are. On the latter portion of the paper, I find it very confusing to try to figure out anything with gap length. It's rather a trivial variable because the gap is a convenience, it is an attenuator but the same gap will act differently for shocks of different amplitude and it will act differently even for shock of the same amplitude and for tests of different dimensions. And I think some of the peculiarities in context, etc. could be straightened out if you had calibrated in cases where you wanted to make a comparison to see what the actual pressure is. I don't think in any case you're going to find one single point evaluation sensitivity that's going to satisfy everything because sensitivity is the behavior toward temperature of the material of a tremendous range of temperature and there isn't going to be any one point single evaluation that will work there.

Mr. Richardson: Donna, I didn't intend to express one single point, the purpose was to bring to light the variables that one might run into when he tries to evaluate any one propellant against another and I think this was pointed out in the paper, if it wasn't, I'm sorry.

Mr. Saffian: You said that the C-4 which you used would not propagate reliably in diameters less than half an inch?

Mr. Richardson: This is unconfined. That's right.

Mr. Saffian: Was this standard C-4?

Mr. Richardson: The bulk C-4, usually made by Holston.

Mr. Saffian: Do you have any idea what density?

Mr. Richardson: 1.5 plus or minus about .05, something on this order

Mr. Saffian: I think if you went to something like 1.5 and above density, you would find that it would propagate reliably in columns less than 1/2" in diameter.

Mr. Richardson: Let's put it this way, we have gone to .6 actually, we got some block materials, we used up all the Navy had and had to

start buying it from Holston. We tried this but were interested in going down slightly below this, and of course if you want to nitpick, you could say 10,000 of an inch or 10th of an inch or maybe 4 tenths of an inch but in people trying to work in some interval, you find that with an 8th of an inch, you just couldn't propagate it. It will propagate within lengths maybe 4 or 5" but then it decays...

Mr. Saffian: The only point I'm trying to make is we had a very successful item based on the fact that C-4 will propagate reliably.

Mr. Richardson: How long is it?

Mr. Saffian: About 2".

Mr. Richardson: It will in 2". There are some other applications with this in some liquid work that is going on. That's why we don't use it because on some occasions the 8th of an inch fail completely. It has propagated as much as 8 to 10" toward decay.

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FIRES DURING MIXING OPERATIONS

by
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We have two incidents to report. Neither of these were disasters in the accepted sense of the word, but both waved warning flags or gave indications of precautions, we believe to be of value to the industry.

The first incident was a fire in a 150 gallon Baker Perkins Vertical Mixer. I believe there has been a growing conviction among solid propellant manufacturers that this vertical mixer would be a bomb.

We realized the mixer was more confining than the horizontal mixer, even though porting is provided in the head of the mixer. (There are four ports of 24 sq. inches each.) In this incident there was a very fast fire. Several things occurred that indicated precautions that might help the mixer to relieve the pressure rapidly. I want to dwell on these points more than on the cause of this particular fire.

The fire occurred after mixing for 38.6 minutes and less than two minutes before addition of the curing agent. The mix had all of the oxidizer and fuel incorporated. Since all mixing operations are performed remotely no personnel were involved.

The bowl was in the mix position and is held there by two hydraulic pistons.

The fire originated at the bottom of the mixer bowl. This in itself, from a confinement standpoint, and from a time-until-sighted-by-the-fire-sensing-elements standpoint was the worst possible condition.

The blow-out panels on the mixer functioned. The additional thrust provided by these nozzles aided in rupturing the hydraulic cylinder on one side and a hydraulic line leading to the cylinder on the other side. The deluge system functioned. These three items we believed saved more serious damage to the mixer, building frame, and the bowl.

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The mixer is located in a steel frame, in a transite covered building surrounded by an earth barricade.

Briefly the following happened; not necessarily in order:

1. Fire originated in the bottom of the bowl.

2. The blow-out port covers flew off, and we had a modified four-nozzle end burner working.

3. The deluge heads functioned properly.

4. The pressure against the mixer head started the bowl down straight. It traveled down at least nine inches without marking or bending the bowl-to-mixer alignment pins.

5. The hydraulic cylinder on the left side cracked open, a hydraulic line between bowl and cylinder on the right side broke. The left side of the bowl started down faster than the right. The pins on the left lift were torn off and thrown; the pins on the right lift were bent inward. The bowl came to rest in a corner.

6. The men in the control room saw a bright flash through the window, heard an explosion, then a hissing sound. The man at the mixer control turned the mixer off.

Apparently a good portion of the mix came from the bowl burning. The fire lasted less than 5 seconds and sounded like a low dull explosion. The fire cloud was a mushroom that went straight up and drifted away hanging together. There was no apparent after-burning of propellant in the bowl or building.

The transite skin wall of the building went with the first puff; roof and all four sides (the doors acted like sails pulling some of the front frame work out of line).

Concerning the main precautions in this operation:

1. We mix by remote control, with posted approved SOP's.

2. We check mixer clearances and running condition on a daily PM check sheet. The check list serves as a release to use the mixer.

3. We use a shadow board in the control house to control all portable tools used on the mixer.

4. We watch the mixer with closed circuit TV.

5. We have a sound system that monitors the mixer. (This has been more valuable than the TV. Although we heard nothing unusual on this occasion.)

Cause: The bowl has a discharge port in the bottom. The closing plug for this port was constructed in three segments. Screwed together, they form a plug unit that seated in the bottom of the bowl. This unit was pulled down and locked into a position by a nut at the bottom of the plug assembly. The plug is stainless steel and sets in a neoprene rubber cylinder one and one-half inches thick. The rubber extends about one-half inch past the side of the stainless steel. There is a flange on the neoprene cylinder that makes the plug pull through the opening very tightly and performs a wiping action as it comes through the bowl opening.

However, should the closing plug assembly ever loosen, from any cause it had no way to go but up into the bowl.

Normally the fit was so tight the rubber had to be coated on the sides with polymer before it could be pulled down. This time it pulled in easily. Action in the mix would tend to unscrew the plug assembly. Once the plug raised 1/8 inch it was not only scraped by the blades but continued to tighten against them. That the scraping was severe is borne out by the scratches on the plug and on the bottom of the fast blade.

There was evidence of both propellant and fire between sections of the plug. The plug measured as being unscrewed 1/8 inch. It was evident that the blades had scraped the stainless steel plug continuously for some time and finally, by friction or impact fired the propellant.

Some of the things we learned:

1. You need as much vent space above the mix as you can get. The blow-out ports should be as large as possible; and the covers that go over them should be as light in weight as feasible. The covers on our ports tore out two deluge heads. There were four lines (eight heads in the mixer).

2. The deluge in the mixer was beneficial. We believe it protected the mixer head and used up some of the heat energy. Deluge heads functioned outside the mixer.

3. The hydraulic system relieved. We believe forcing this system to relieve would be advantageous.

4. The skin wall on the building itself functioned perfectly. It was economical to construct originally. It was simple and fast to repair, and in this case it vented pressure fast and efficiently.

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Frame of Building Showing Preparation for Skin Wall

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Building Before Fire

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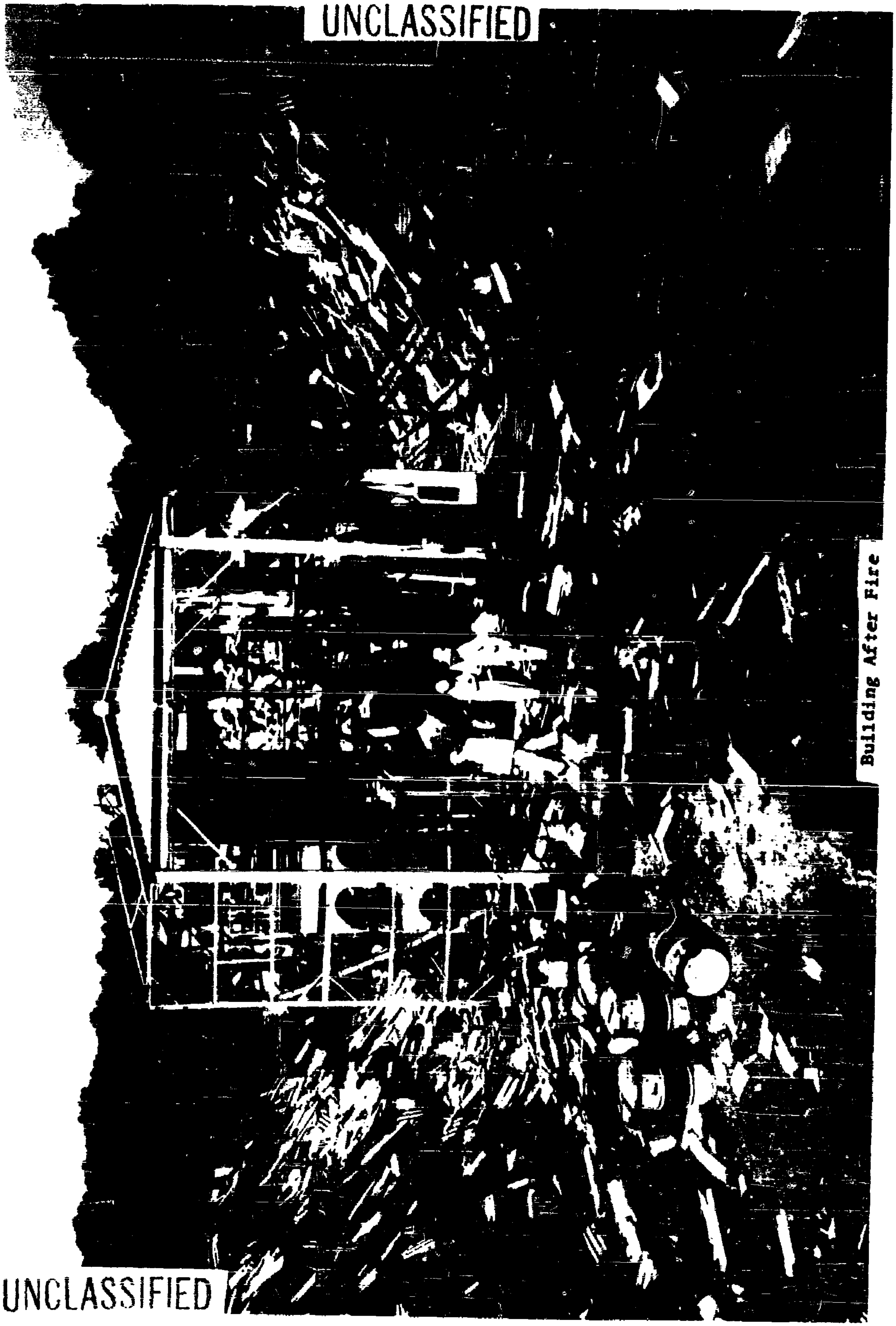

Building After Fire

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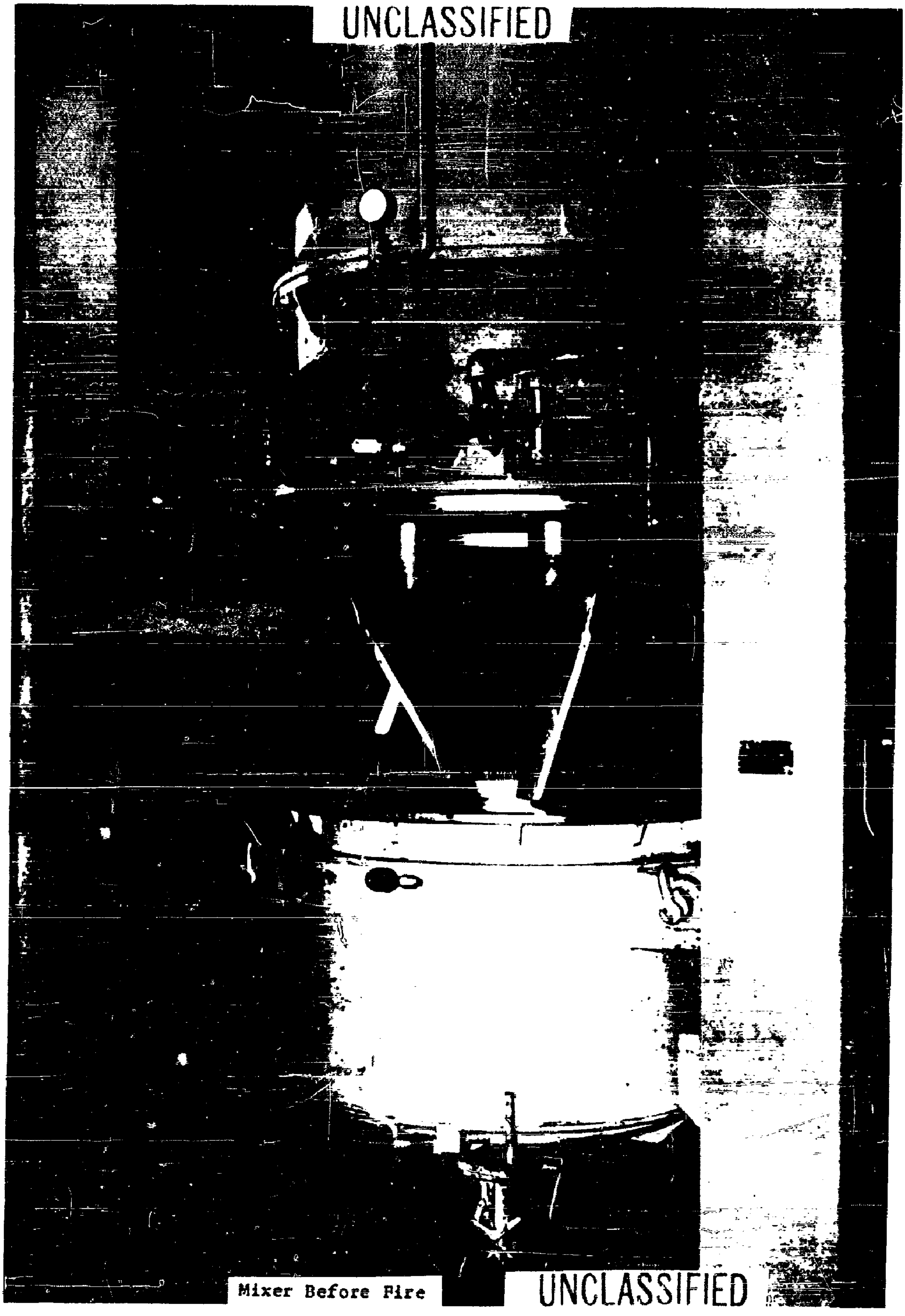

Mixer Before Fire

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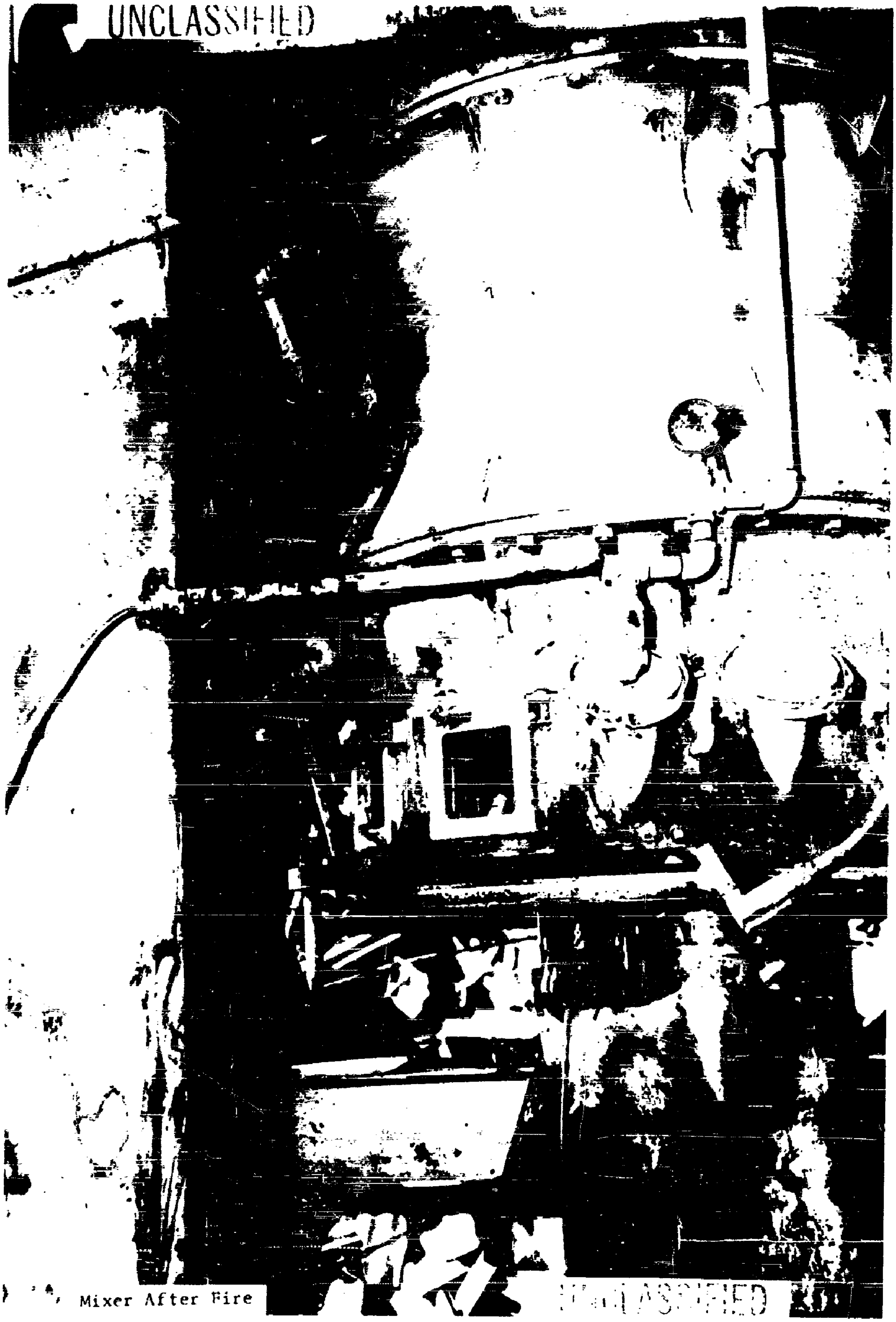

Mixer After Fire

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Bowl
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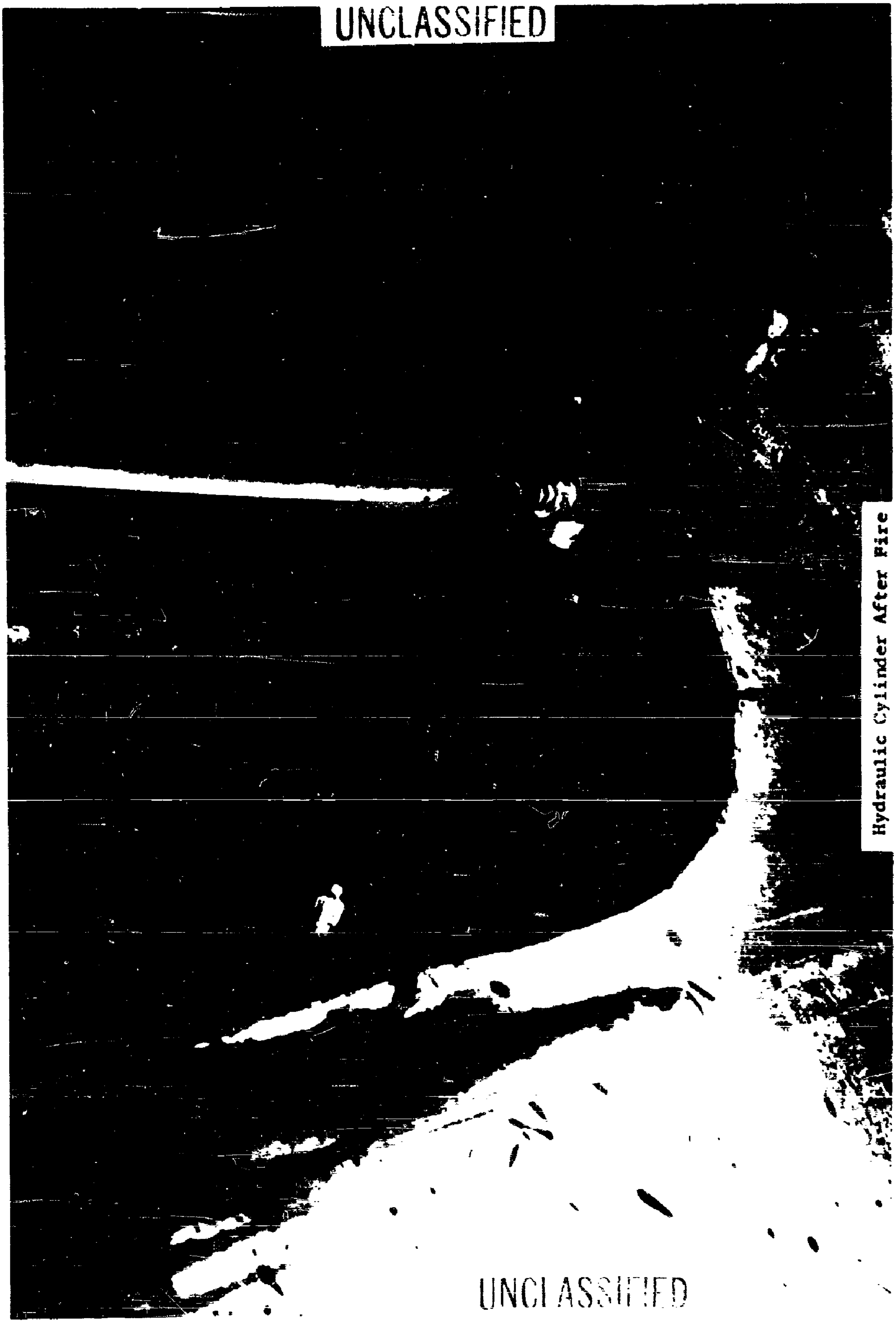

Hydraulic Cylinder After Fire

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Hydraulic Cylinder After Fire

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Bowl Interior

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Plug Assembly

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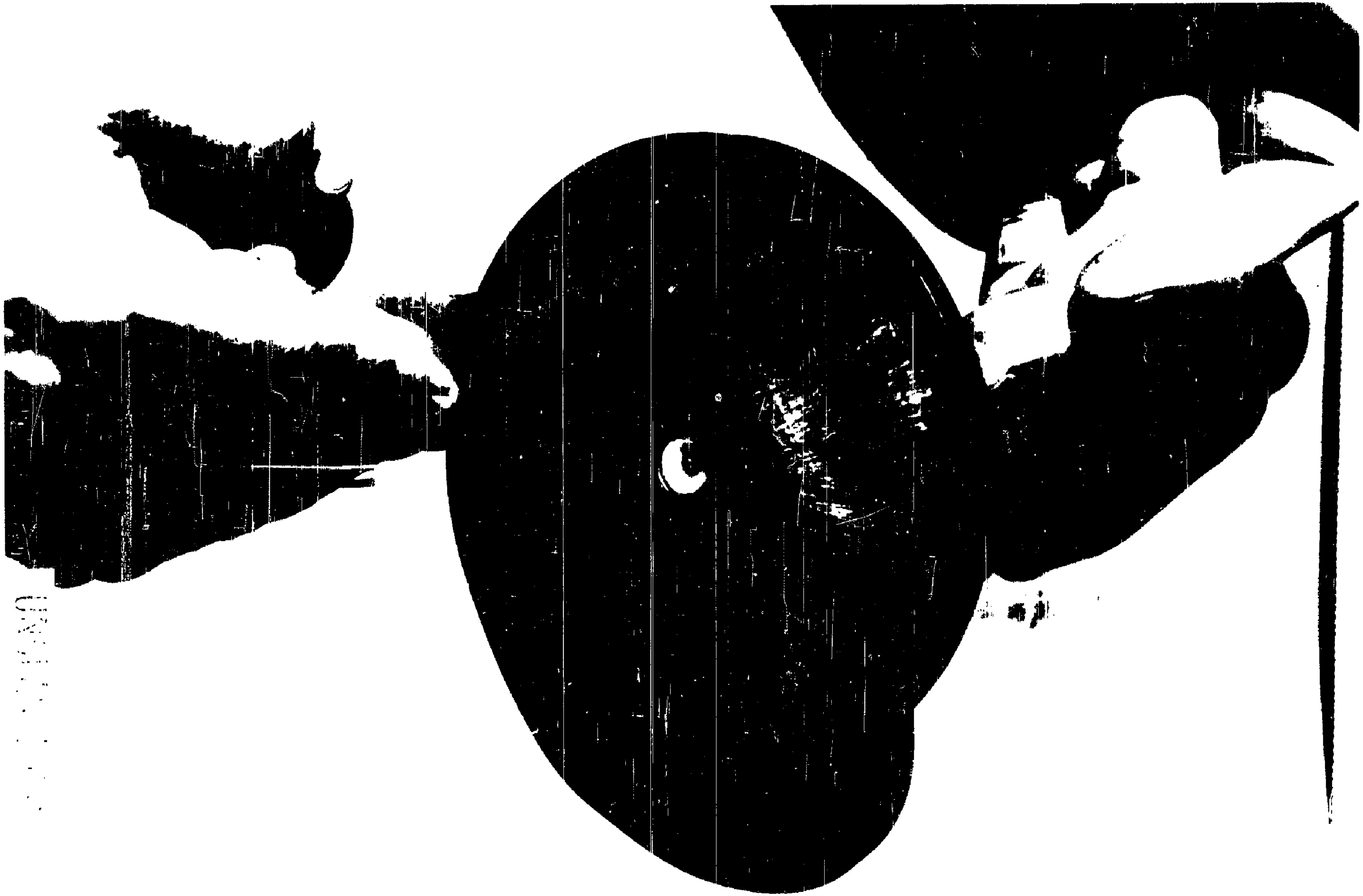

Top of Plug (Closeup)

As a result of the fire we redesigned the plug assembly. We also:

1. Returned the deluge system to the bowl interior. We had been doubtful of the value of the system before the fire. The fire made us believe it to be beneficial.

2. Replaced the skin wall with no principle changes except to place a steel shield between the mixer bay and the utility lean-to.

3. Lightened the port covers over the blow-out ports.

4. We wish yet to install a reliable system that will rupture the hydraulic cylinder.

I would also like to make the following comments:

We still prefer the vertical mixer. We believe it can operate with greater clearances than a horizontal type (1/4 inch for example). We know it to be easier to clean. It has a better mixing action - faster. This in spite of the fact that we cut its original blade speeds. From a production standpoint its bowl-off bowl-on feasibility make it a much more prolific batch type mixer.

The second incident also was a mixer (or mixing) incident. It was much less damaging to facilities, but more tragic in its result. It brought out forcefully, the results of an exotherm between a curing agent, MAPO Tris(1-(-2-methyl) Azridinyl) Phosphine Oxide and uncoated oxidizer.

We were aware there was an exothermic action between these two materials; but this fire occurred in a much shorter time (two to four minutes after the curing agent was added) and at a much lower temperature (200 degrees F in the mixer walls) than we had any understandings of previously. (None of our lab tests previously had shown the possibility of a fire this fast at a temperature this low.)

The mixer involved was a horizontal Beken Mixer, 5 gallon size. The blades are multi-wing overlap. The mixer glands are repacked once per week, and had been packed three days before this incident. This was the fifth mix after packing. The mixer has all blade clearances checked after the last batch on one day and before the first batch the next day. These had been performed and all clearances were on tolerance.

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Building After Incident

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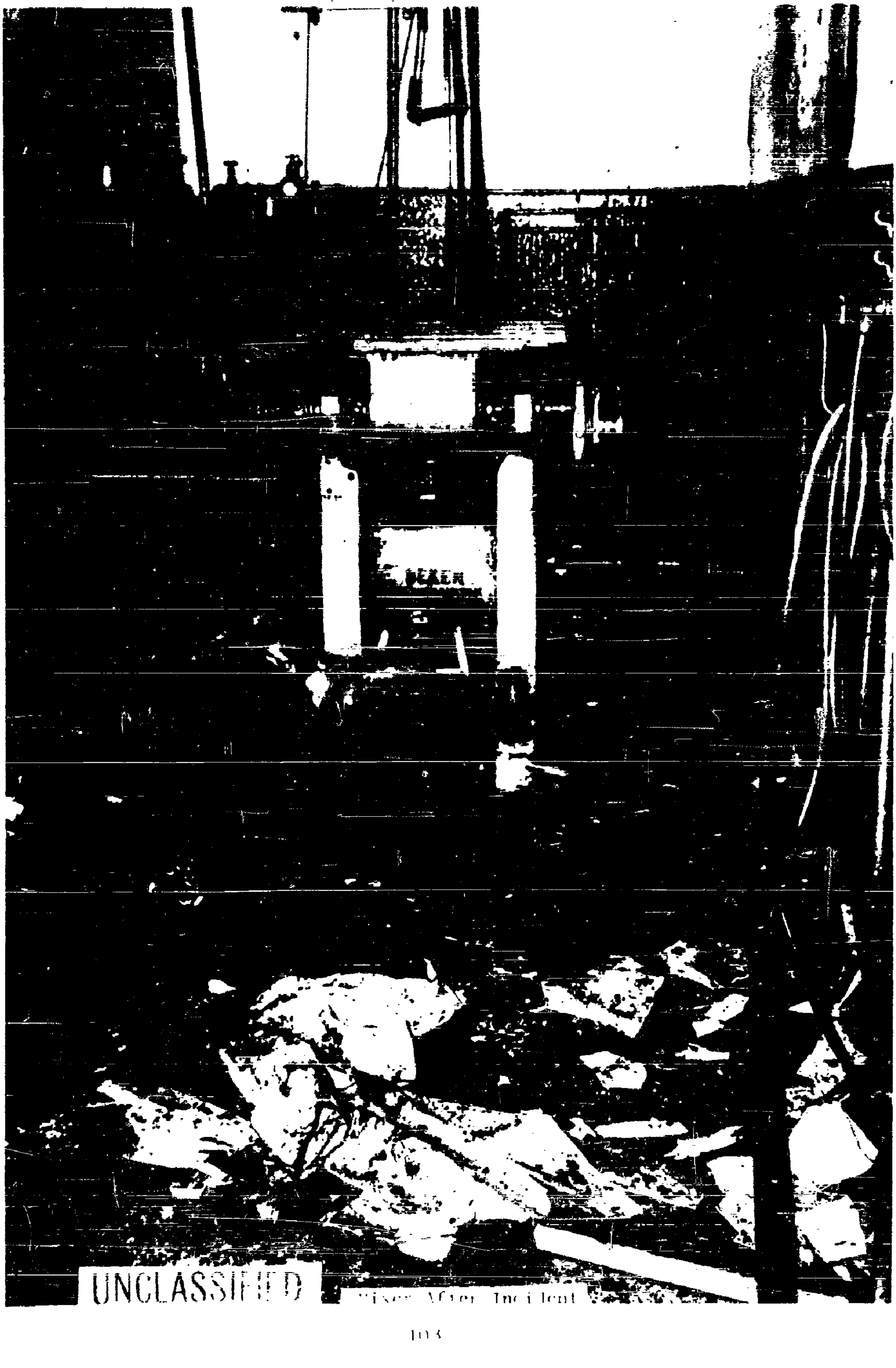

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Mixer After Incident

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Mixer

Mix Bay Walls

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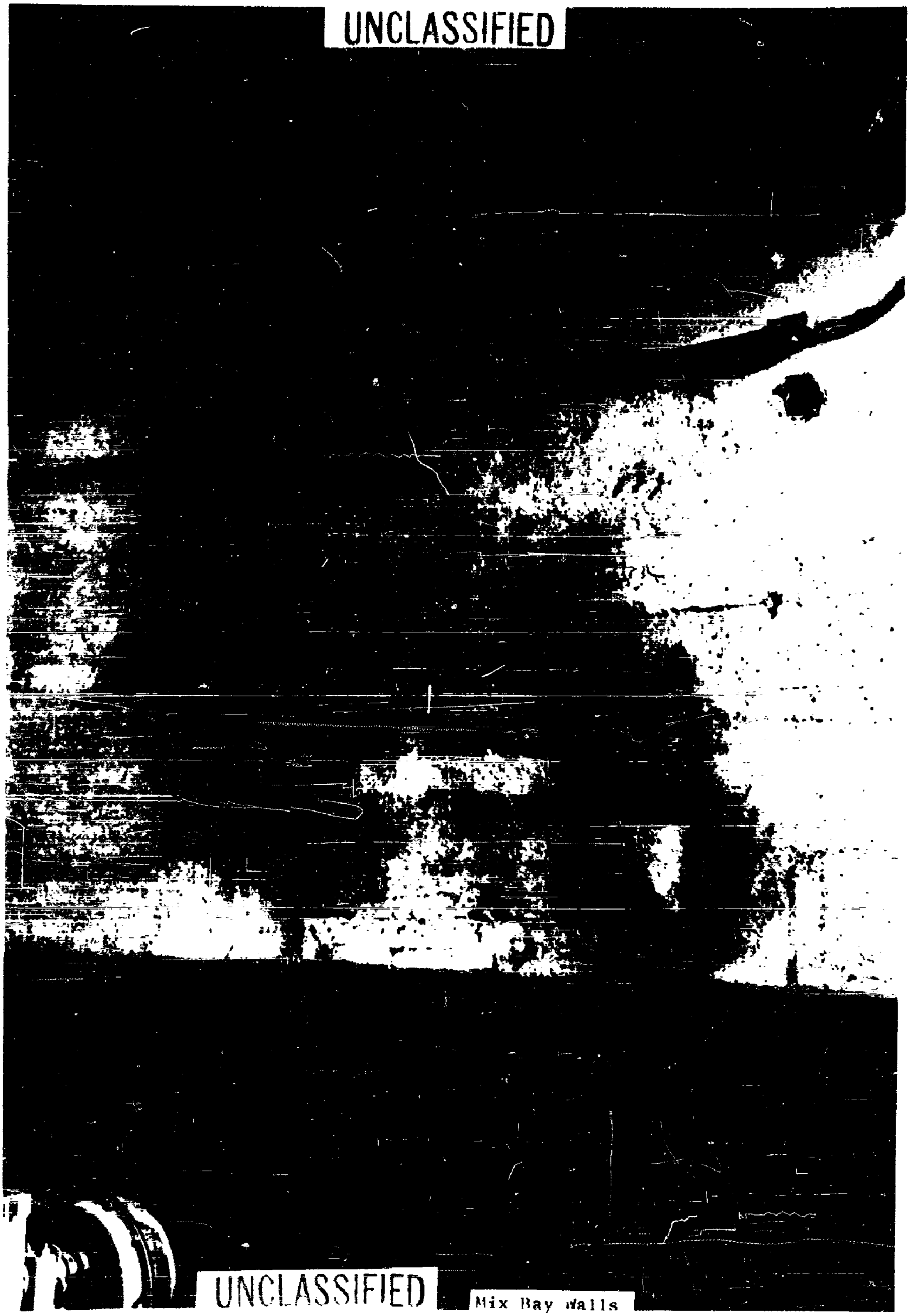

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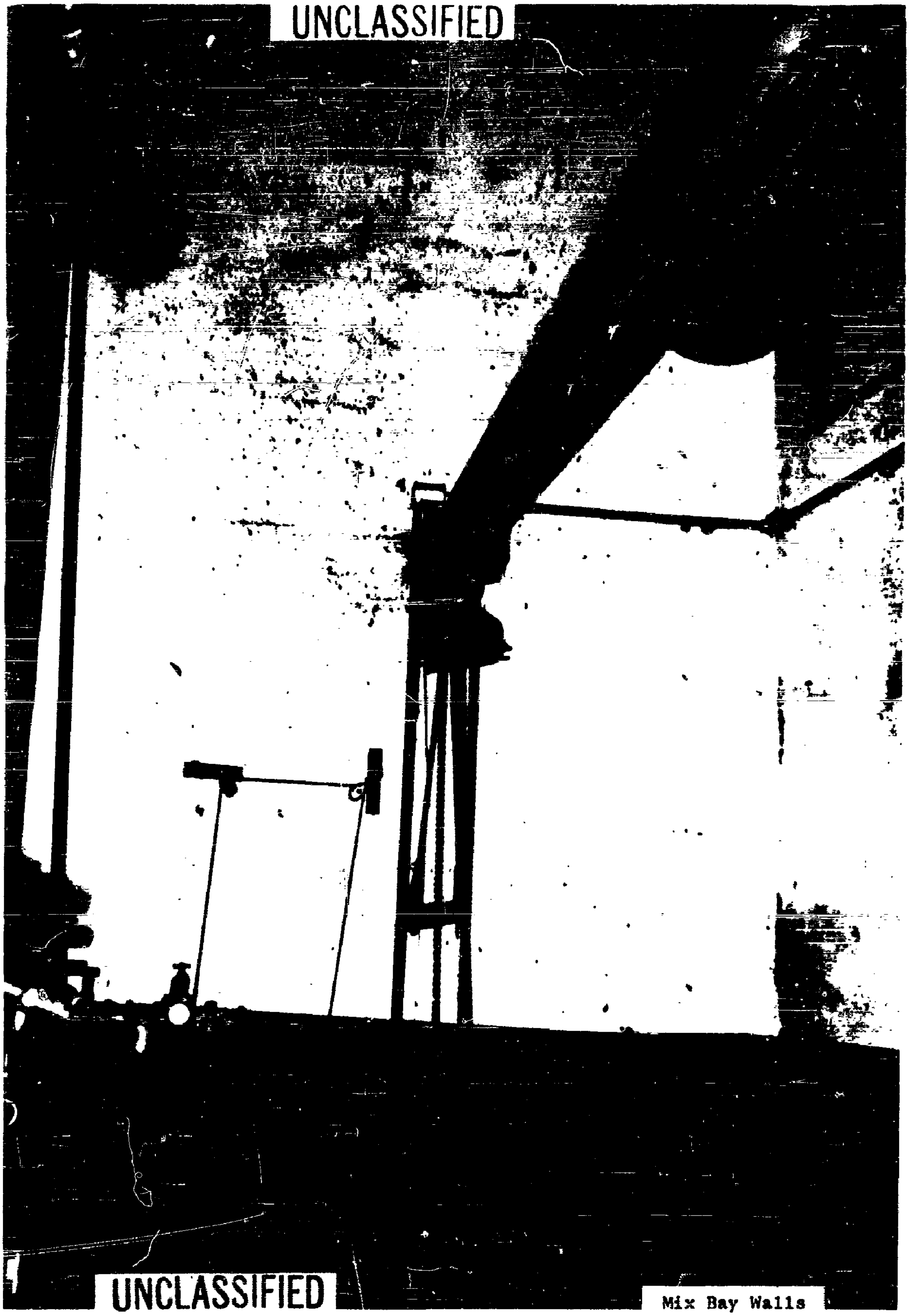
Mix Bay Walls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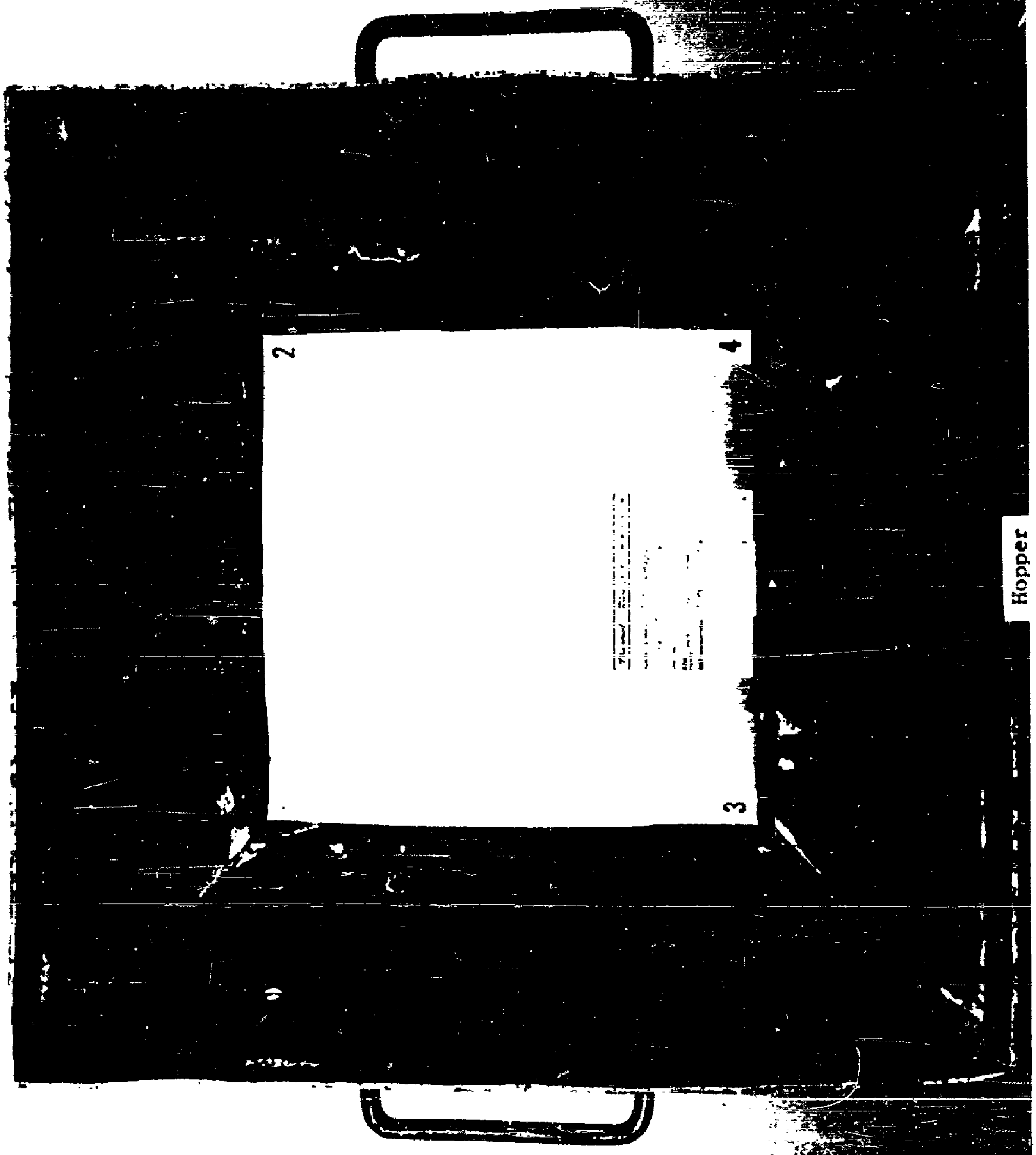
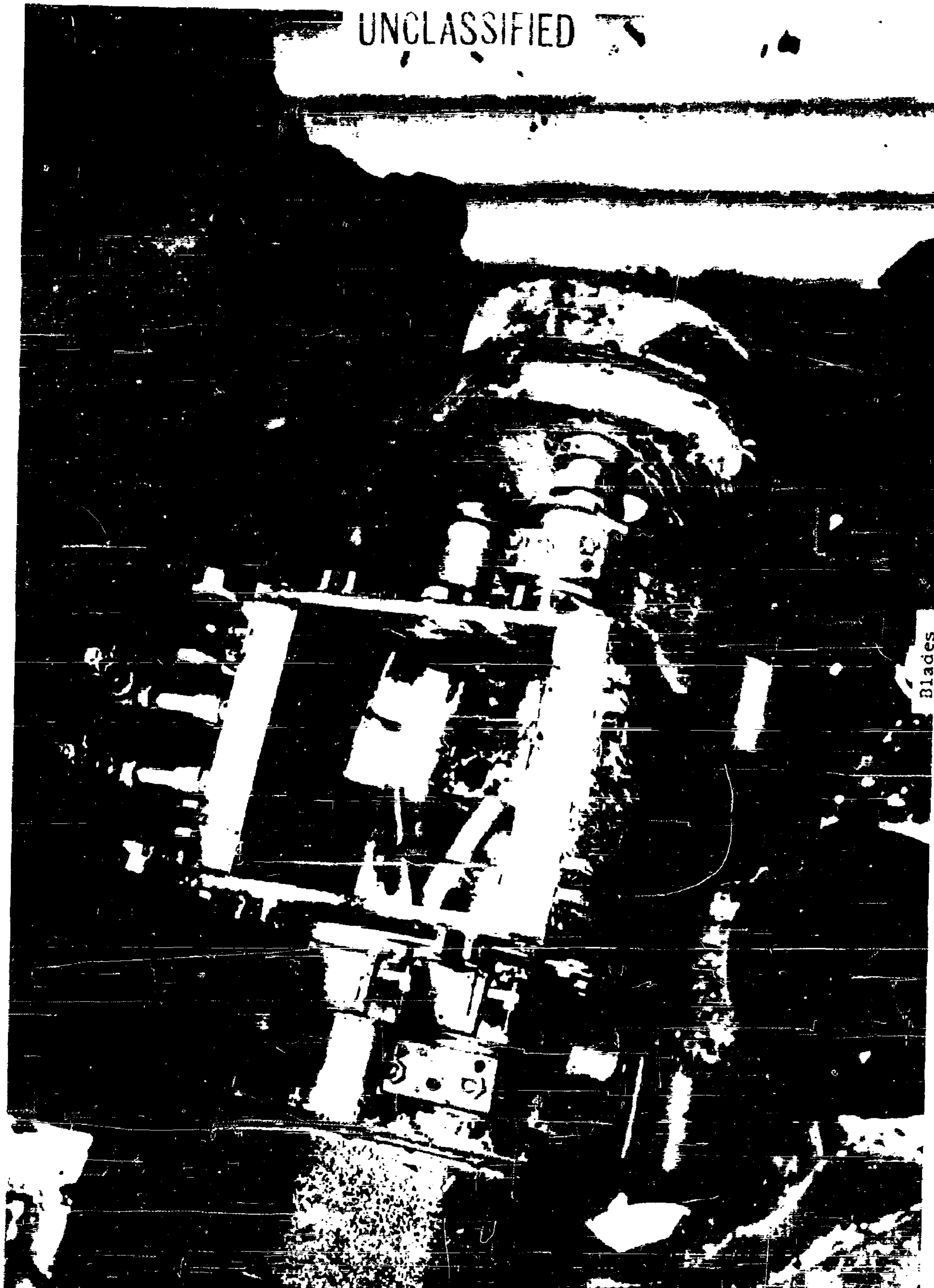
Mix Bay Walls


Hopper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Blades
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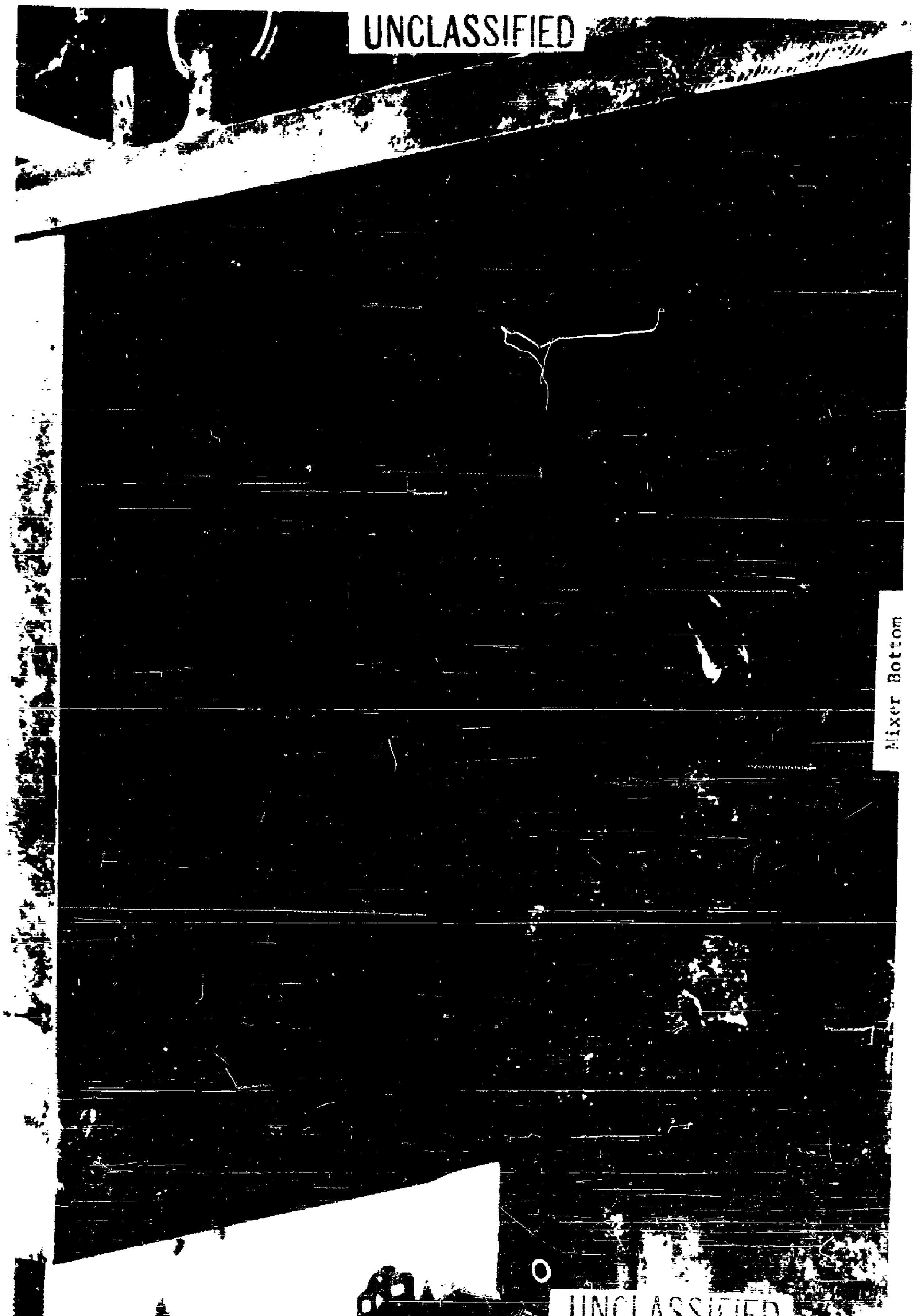
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Mixer Bottom
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The mix progressed normally through incorporation of oxidizer and fuel. At this point two operators entered the bay to scrape down the side walls and add the curing agent (MAPO) prior to the finishing run of the mix.

This particular mix was unusually stiff. Also, some oxidizer was present on the sides of the mixer and more had been trapped between the funnel and side walls. This was scraped off and distributed over the top of the mix "to make it incorporate faster."

The curing agent was poured on top of the mix; spiraled from the center toward the walls. A spatula of propellant was taken from the mix and used to wipe out the MAPO can. The operator who was performing this operation is thought to have reached for a second spatula of material, when the mix erupted in a fast burning action. This was without warning. Neither operator, the one over the mixer or the one beside it, had an opportunity to move.

The fire apparently started on the bottom of the mixer. The mix was thrown from the mixer in one flash. The fire cloud went straight up; according to observers, "sparkling," as it went. It left streaks of unburned propellant on three walls of the bay. The operator over the mixer was hit by propellant.

After the fire there was a film of propellant on the mixer walls and blade tops. In fact everywhere in the mixer but under the front blade and bottom of the mixer under the front blade (which areas were burned clean).

Neither operator had any indication of anything wrong. Neither moved prior to the incident (to get away). The men were in the bay approximately ten minutes. The fire occurred in from 2 to 4 minutes after the curing agent had been added.

In subsequent tests of MAPO and AP in the lab we had fire occur in two minutes within the temperature probabilities of the mixer wall temperature (200° F).

Cause: Reaction between MAPO and uncoated oxidizer which we believe flowed down the mixer walls to the bottom of the mixer and ignited.

The following changes were made:

1. MAPO or any amine curing agent must be put into the mixer diluted (pre-mixed) with 90% of the total mix polymer.

2. Deluge was placed in the bay. We do not believe it would have put out the fire but it might have helped the operators.

3. We now require a monitor - who will not enter bay to stand by while operators are in the mixer bay.

4. We designed a suit that will offer more protection. One feature is that the operator can break out of it with one motion.

5. Designed a flameproof apron that snaps to the bottom of our face shields.

In ending I would like to make two observations. In regard to the 5 gallon mixer incident, we had tested the compatibility of the materials in the lab. These tests either had not been complete enough or there was enough difference between lab methods and quantities and production methods and quantities to lead us into an incident we were sure could not happen. I would warn everyone that continued tests as materials, or methods, or amounts change are necessary if we are to avoid incidents like this one.

Secondly, we now on all development mixes run a small pilot batch (same temperatures, same mix methods, same lot of materials) eight hours ahead of the production development mix. Any malfunction or problem in the pilot batch is cause to cancel the production development mix. This is followed only until feasibility is established.

Mr. Bishoff: On the first accident, you indicated that the fire started at the bottom of the kettle and then you said that the deluge system was effective. What's your theory on how the water got to the seat of the fire in order to throw it off.

Mr. Stuckey: I don't think it ever got to the seat of the fire. I think that we had the fastest acting flooding we have ever had and converted so much of this heat to steam and laying a layer of water over the head of the mixer, I think we protected the entire mixer. I think this is all we accomplished out of it. We used up a lot of the energy, we protected the head of the mixer with water. We started out with eight valves open, we ended up with four. We've thrown a lot of water into the head of that mixer.

Unidentified, JPL: I was just wondering if you could go into more detail in this last incident of the composition of the material at the time the incident happened, in other words, was the polybutadiene

type polymer thoroughly mixed? You mentioned that you thought the mix had trickled down underneath and that you had a viscous putty-like mix. How did this happen?

Mr. Stuckey: If it had been just putty-like, this would not have happened. This was a highly loaded mix - it was very stiff, in fact the operator at the end of the first scrapedown, when he had half the oxidizer in, had gone in to report that it was unusually stiff, it was still stiff after the second increment of oxidizer and the last one incidentally had been added. In fact, the operators when they scraped the sidewalls down, stuck their spatulas along the sidewall of the mixer and pulled the propellant up from the side and it just stayed up there. When the blades had come up, they left cavities behind the blades, it was very stiff.

Mr. Jezek: What water pressure do you have on those deluge lines and in the second incident, did the man have a face shield on at that time or was he just bare-faced?

Mr. Stuckey: He had on goggles. We went to face shields shortly after that. Water pressure - 50 pounds, not very high. This is a two pronged system on the jets - this fast-acting squib-activated set-up that we have. In fact under the prongs we cut the time from 600 milliseconds to 200 milliseconds.

Mr. Nolan: Did your building have a sprinkler system in it? The reason I'm wondering is that we've had several incidents at ABL in which the sprinkler system rather than providing protection, acted as a casualty producer by the missiles it produced when we had the explosions.

Mr. Stuckey: Let me start off by saying I don't like deluge systems, we use too many of them. We didn't have them except in the mixer bay itself and in the mixer superstructure and the two systems were tied together. The one in the bay probably put out the outside outfit.

PROPELLANT MIXERS

by
James B. Settles
Hercules Powder Co.
Wilmington, Delaware

No propellant mixer is sufficiently versatile - and safe - that it can be considered a completely universal propellant mixer.

No propellant mixer is so versatile - and safe - that any formula, of any sensitivity, of any viscosity can be satisfactorily and safely processed in it.

A statement which is so arbitrary in tone and content as the one just made is certain to provoke arbitrary and contradictory responses. Some manufacturers of mixers will probably disagree with the statement; some manufacturers of propellants may disagree with the statement.

However, there is supporting justification for the statement, and one of the objectives of this discussion is to present that justification. This portion of the discussion will attempt to relate safety to quality, with important variables affecting both being the viscosity and sensitivity of the material being processed.

Another objective of this discussion is to describe a type of mixer that has been under investigation by Hercules Powder Company for the last couple years. This mixer appears to have advantages in the processing of sensitive ingredients that may be of general interest.

It is important that there be some understanding of the types of mixers which are generally used in the manufacture of propellants. It is not intended at this time to extend this discussion to mixers used in processing high explosives, such as Talley Bowls; or ingredient processing equipment; such as Shreader Bowls, or the broad range of ribbon mixers. The types that will be discussed are those used in the final processing of propellant formulas, including the following:

One of the oldest and most commonly used is the conventional horizontal sigma-blade mixer. There are a number of modifications in mixer designs which use a horizontal agitator, including nobbin blades, segmented blades, etc. It is important to note that most mixers with horizontal agitators have gland areas which are, at times, submerged in the materials being mixed.

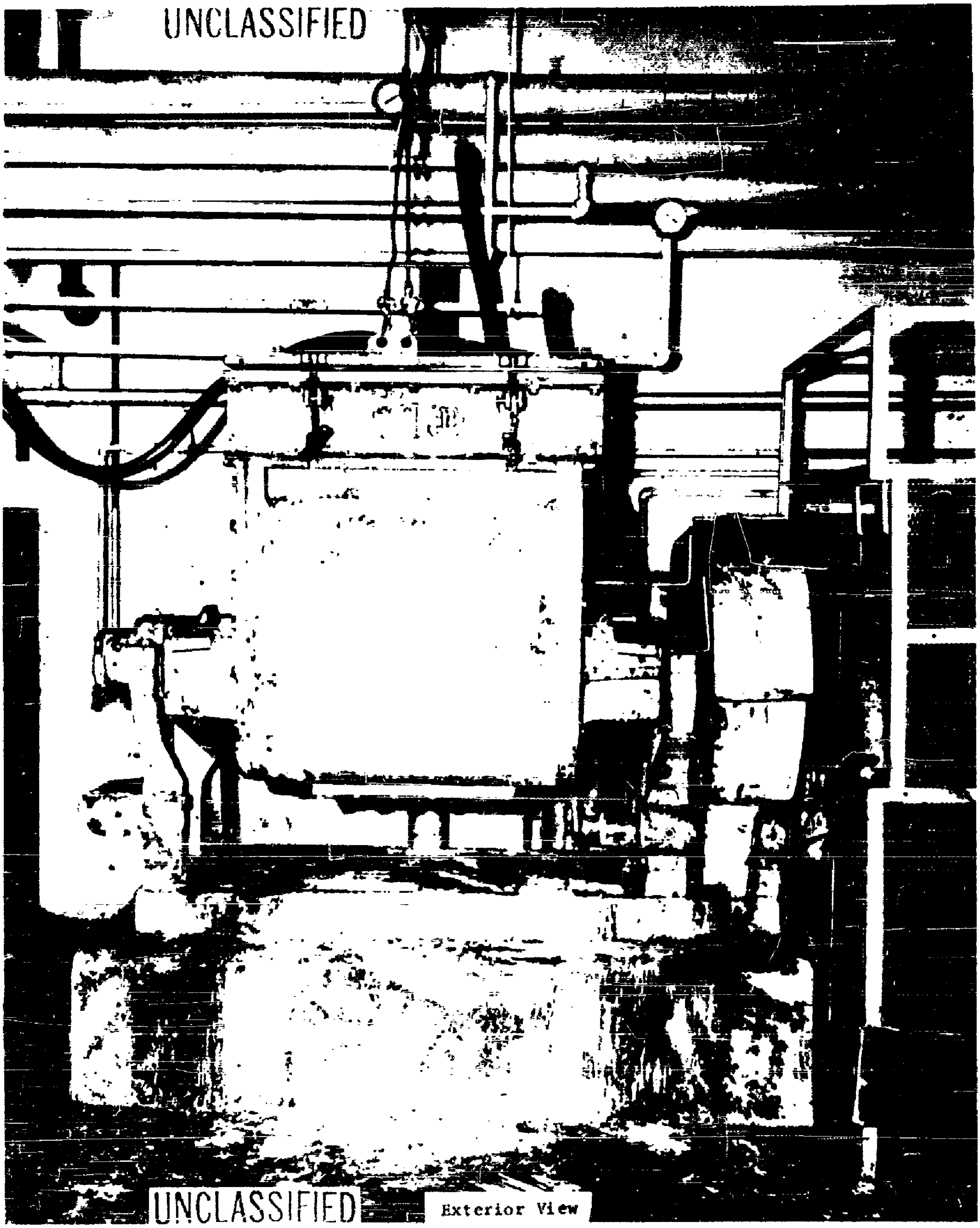
There are several types of mixers in more or less general use which utilize agitators that are oriented vertically. These include the single-planetary mixer, the double-planetary mixer, and the turbine-blade mixer. The gland areas of these vertical mixers are always contained in housings which are located above the level of the material being processed.

There is another type of mixer which has received some attention in recent years that may be neither vertically nor horizontally oriented, and it does not utilize an internal agitator. This is the mixer which Hercules has had under development for the last couple of years, and we refer to it as a "barrel" mixer. Its use is particularly attractive in the processing of friction-sensitive materials; and most solid propellant formulas are friction-sensitive to some degree.

The "barrel" mixer, and its advantages as a means for safely processing sensitive propellant formulas, will be covered in considerable detail during this discussion. Despite its safety advantages, the "barrel" mixer is <u>not</u> being represented as the ultimate for propellant processing. To emphasize this point, let me restate the introductory remark to this discussion.

No propellant mixer is sufficiently versatile - and safe - that it can be considered a completely universal propellant mixer.

The point will be clarified by a more detailed review of mixers. Consider the old conventional horizontal sigma-blade mixer.



Exterior View

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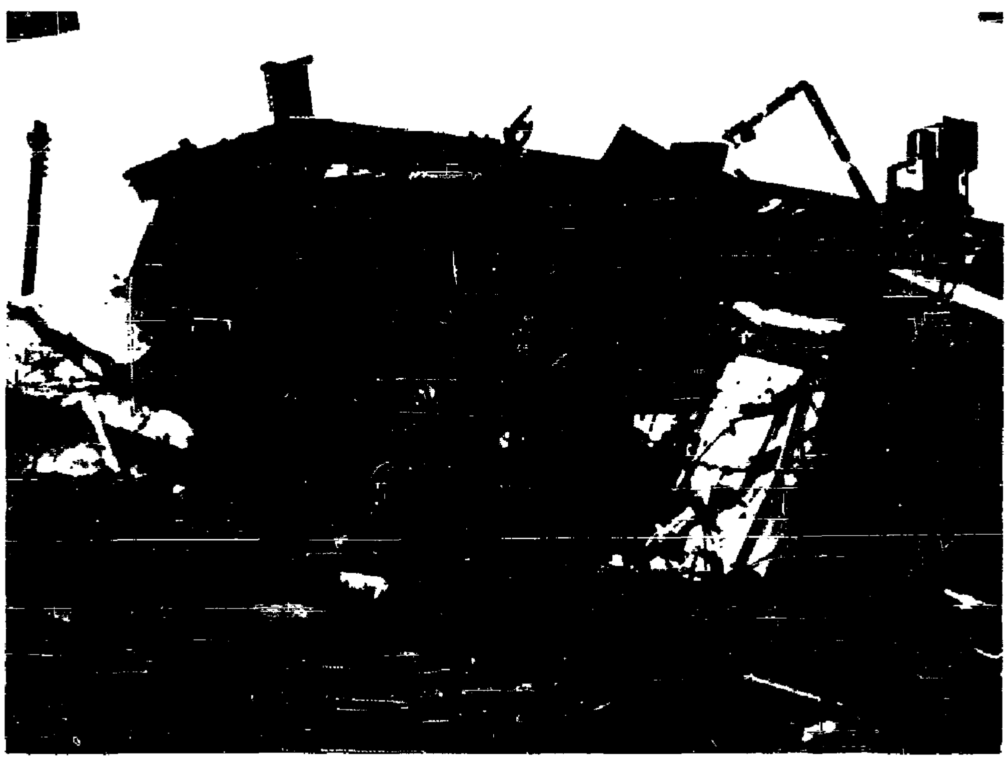
Interior View

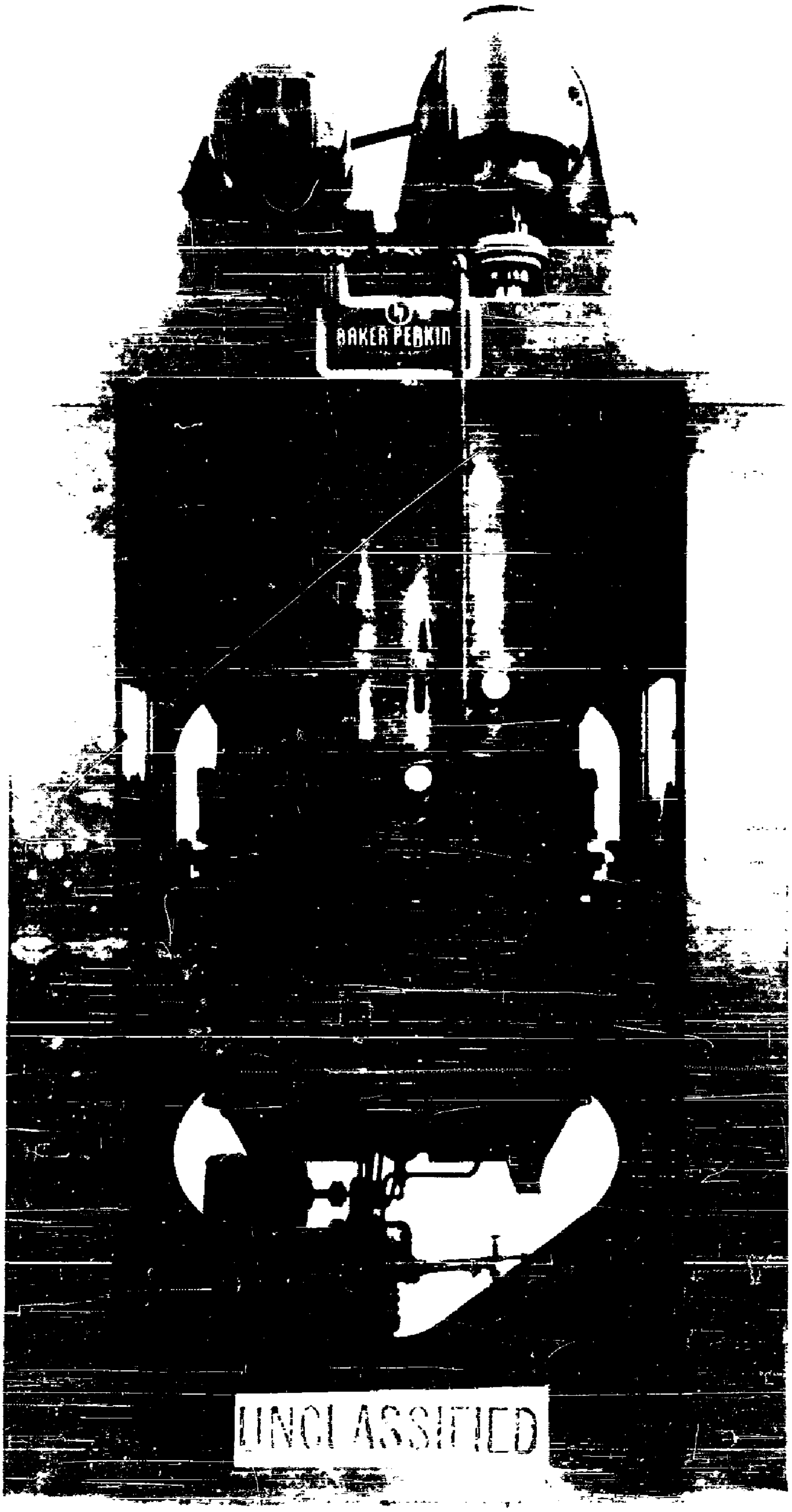
Millions of pounds of propellant formulas, both detonable mixes and non-detonable mixes, Class 9 and Class 2, have been processed in this type mixer. The clearances between the blade and the bowl usually are set somewhere between .100" and .200". The action of the opposing sigma blades impart both shearing and kneading forces to the matrix being processed. Some reduction in ingredient particle size may also be encountered. The action of this mixer is vigorous, and with adequate horsepower in its motivation source, this type mixer can adequately cope with matrix viscosities in excess of one million centipoise.

It is important to note that optimum mixing action is obtained when the level of ingredients in the mixer is well above the horizontal centerline. Under such conditions, it is obvious the gland areas are submerged in the ingredients and are subject to contamination, as these ingredients migrate to points of lower pressure. If friction-sensitive materials are being processed, a serious safety problem will exist and the results may look something like the following slide:



Mix House After Explosion

The desirability of getting away from submerged glands in propellant mixing has been appreciated for some time, and this desire can be accomplished by utilizing a double-planetary vertical mixer.



Exterior View of Mixer

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Same Mixer, Bowl Removed

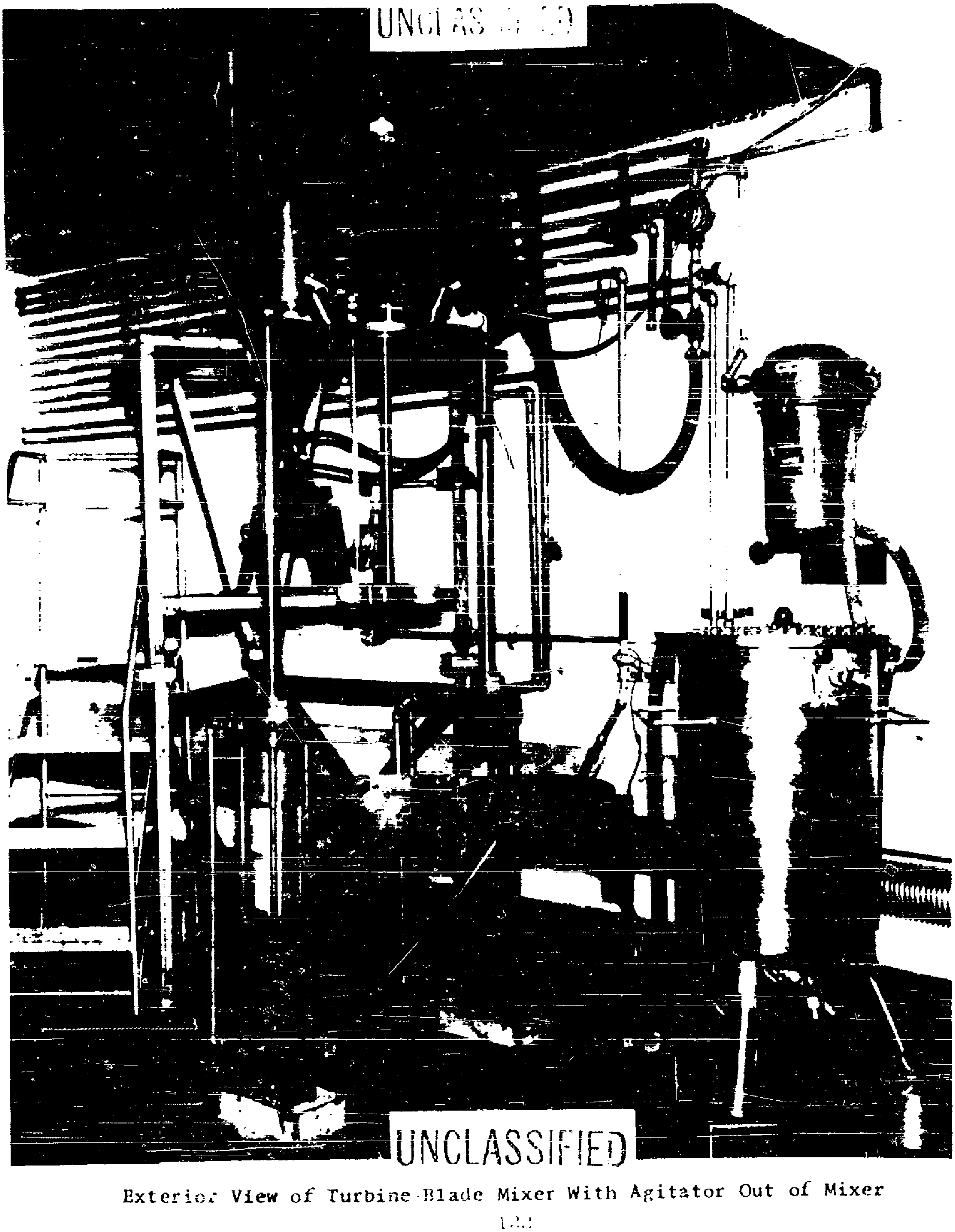
BAKER S-591 SAGINAW

It is very obvious this type of mixer does not have submerged glands; it also has the capability of accomplishing adequate mixing with greater blade-to-wall clearance than a sigma-blade mixer. Because of the double-planetary action of the blades, it can accomplish adequate mixing of the materials at relatively low speeds; and the matrix viscosities it can handle are a direct function of structural adequacy and power input. These viscosities can be well above one million centipoise.

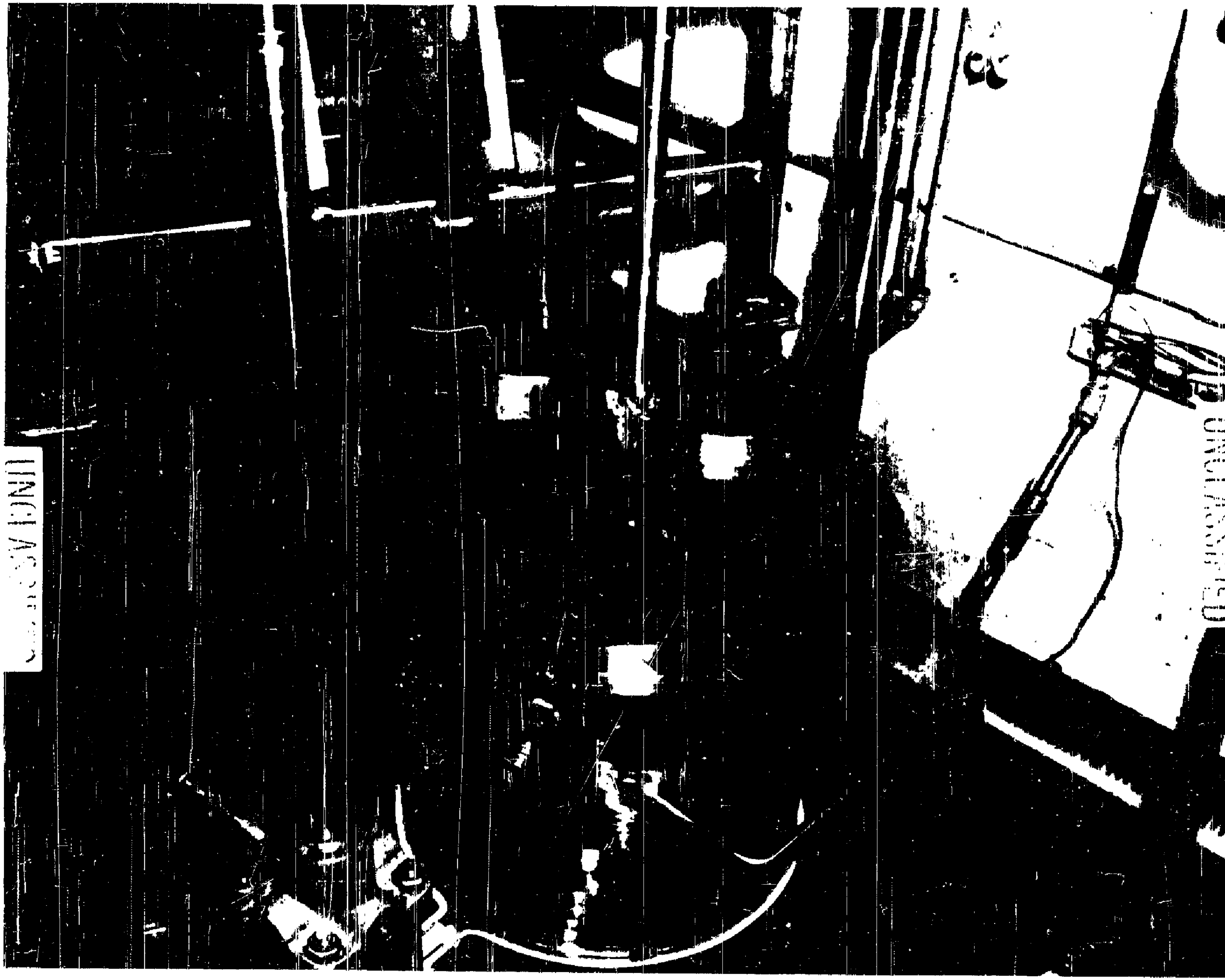
However, this type of mixer does have some safety deficiencies. Its design places massive quantities of steel directly above the sensitive ingredients, and an incident of disaster proportions would reduce this metal to very lethal missiles - and a lot of them. Also, the overhead location of the gears and bearings poses a potential for contamination by sensitive dusts which may be generated during the mix cycle.

A single-planetary vertical mixer has most of the desirable attributes of the double-planetary type. I do not have a picture of this mixer. It is very similar to a double-planetary, except that there is only one blade, and it does not have submerged glands. It can perform adequate mixing with smaller quantities in the mixer and greater blade-to-bowl clearances than a horizontal sigma-blade mixer. Its action is not as vigorous as a double-planetary mixer, and the viscosities of matrix it will competently handle are somewhat less than a double-planetary mixer and numerically would probably be under one million centipoise. It also has the disadvantages of a considerable mass of metal directly above the sensitive materials in the mixing bowl, and its principle working parts are located in a region which makes them susceptible to dust contamination.

The turbine-blade vertical mixer corrects some of the deficiencies of the single and double-planetary machines, but it encounters other deficiencies that are questionable from a safety viewpoint.



Exterior View of Turbine-Blade Mixer With Agitator Out of Mixer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Interior View of Same Machine With Agitator Suspended Above Mixer

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It is to be noted that the highly objectionable mass of overhead metal that is an inherent part of single and double-planetary mixers has been appreciably reduced in the turbine-blade approach. Also, the dust problem that may be a part of some propellant formulas, can be more readily controlled by such techniques as air-sparging of gear boxes. An additional and favorable safety factor is the larger blade-to-bowl clearances that are possible with this mixing principle. The clearance may be as great as two to three inches for some formulas of low viscosity.

However, the improvements that are possible with the turbine-blade mixer are purchased at price. This price is a drastic increase in blade speed, and a decrease in the range of matrix viscosities which can be satisfactorily processed.

The sigma-blade and planetary mixers may have blade speeds as low as fifteen to fifty rpm--or only a hundred or so linear feet per minute. To compensate for reduced area of coverage, the turbine-blade mixer may require speeds of rotation at the tips of the blades of several thousand linear feet per minute. If ingredients are being processed that are unusually friction-sensitive, such agitator speeds may be completely intolerable.

Another adverse consideration with turbine-blade mixers is a limit in viscosity above which increasing blade speed is completely ineffective as a means of improving quality of mixing. A point of viscosity can be reached where the blades cut through the material being processed without any interaction being accomplished. The maximum viscosity which can be handled with a turbine-blade mixer is probably below 300,000 centipoise.

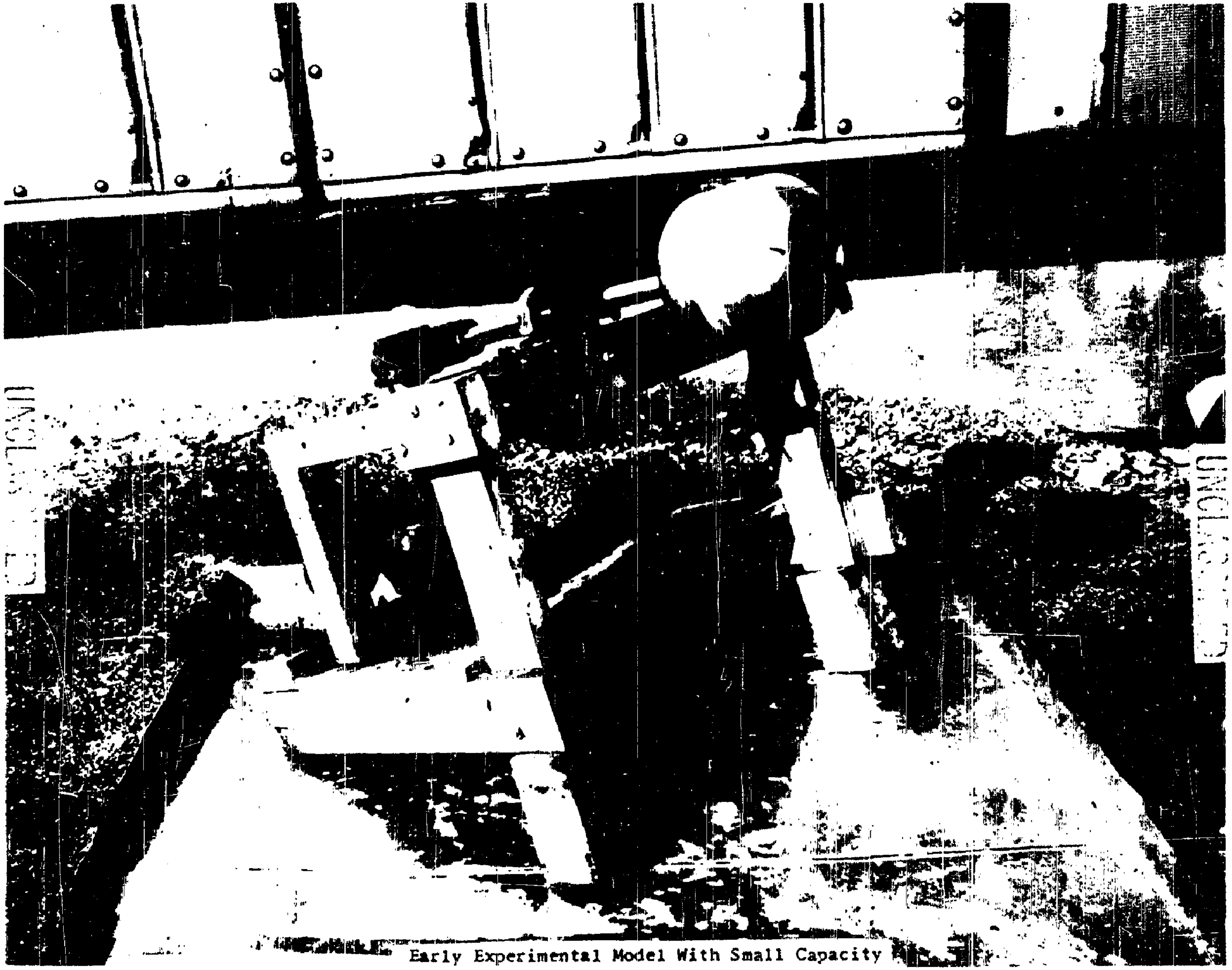
Even when we look at the broad parameters of mixing which have been discussed so far, it isn't too hard to grasp the point that each type of mixer has advantages and disadvantages. The characteristics of a mixer that may be advantageous from the viewpoint of quality may be a very serious disadvantage from the viewpoint of safety: such as speeds of agitator rotation or blade-to-wall clearances. These contradictory considerations strongly support the premise that there is no completely universal propellant mixer.

It is obvious a mixer must be able to satisfactorily cope with the viscosity of the matrix to be processed. It accomplishes this by a combination of shearing, compressing and inter-distribution of the ingredients. The heat-of-friction generated by these actions may be too great to be tolerated. In which case it is obvious the formula is too hazardous to process by conventional means.

The heat-of-friction may be generated by conditions other than the agitators passing through the material being processed; such as the heat-of-friction generated by metal-to-metal contact within the packing gland area; or the heat-of-friction generated by foreign material between the agitator blades and mixer bowl. These potentials present design problems which should be very carefully evaluated. Answers to these problems may lead to a mixer specially designed to cope with a combination of safety and quality problems and the result may be somewhat of a departure from the conventional.

It was such a combination of requirements that lead Hercules Powder Company to concentrate design attention on the "barrel" mixer. This mixer, too, has its advantages and disadvantages. One limitation that should be understood immediately is that matrix viscosities of greater than 200,000 centipoise will not process well in this type mixer. We believe it has superior safety and processibility characteristics for viscosities below that level.

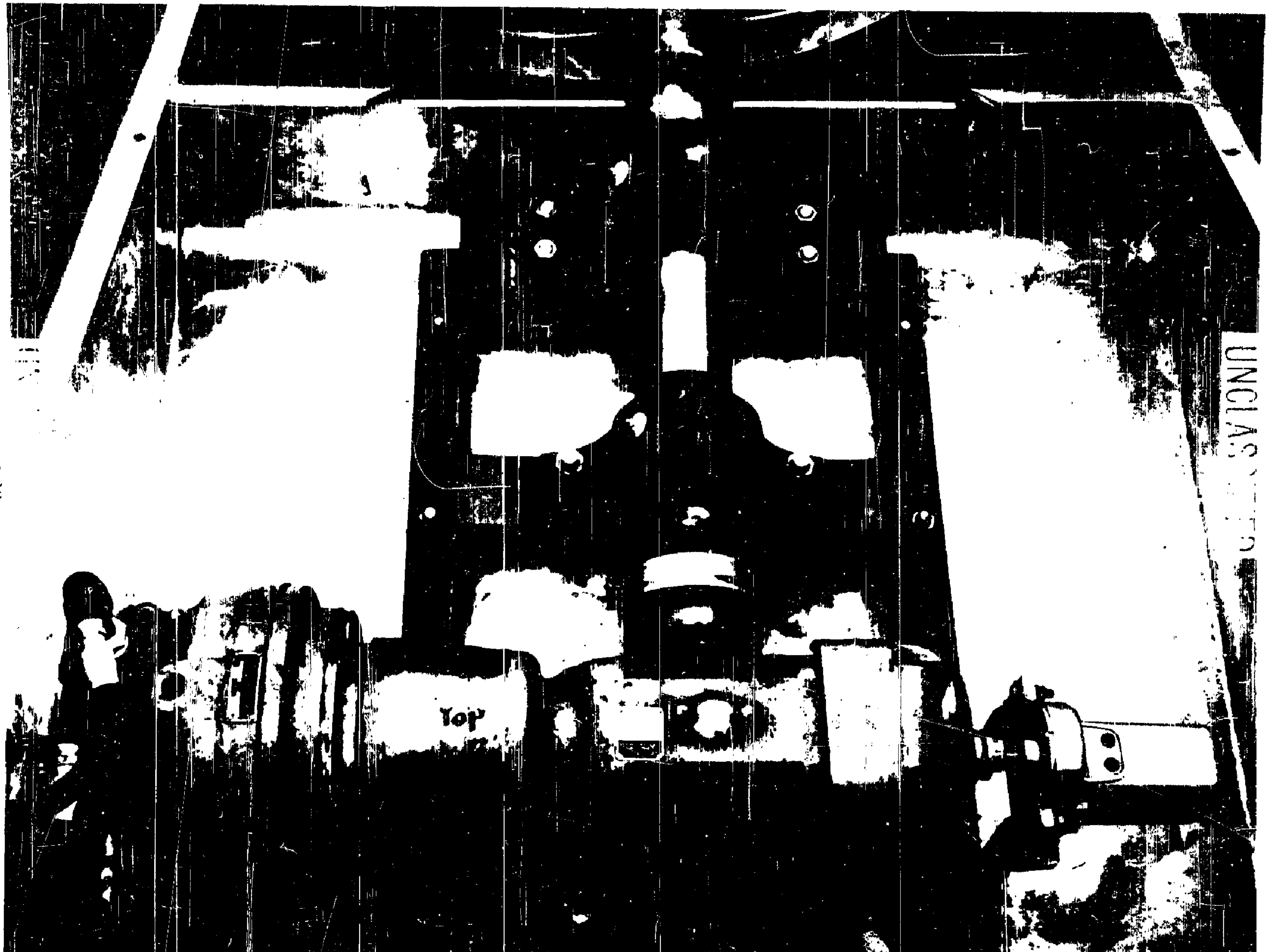
You will be interested in specific details about the mixer.



Early Experimental Model With Small Capacity

Front Angle of 500 Pound Capacity Production Mixer

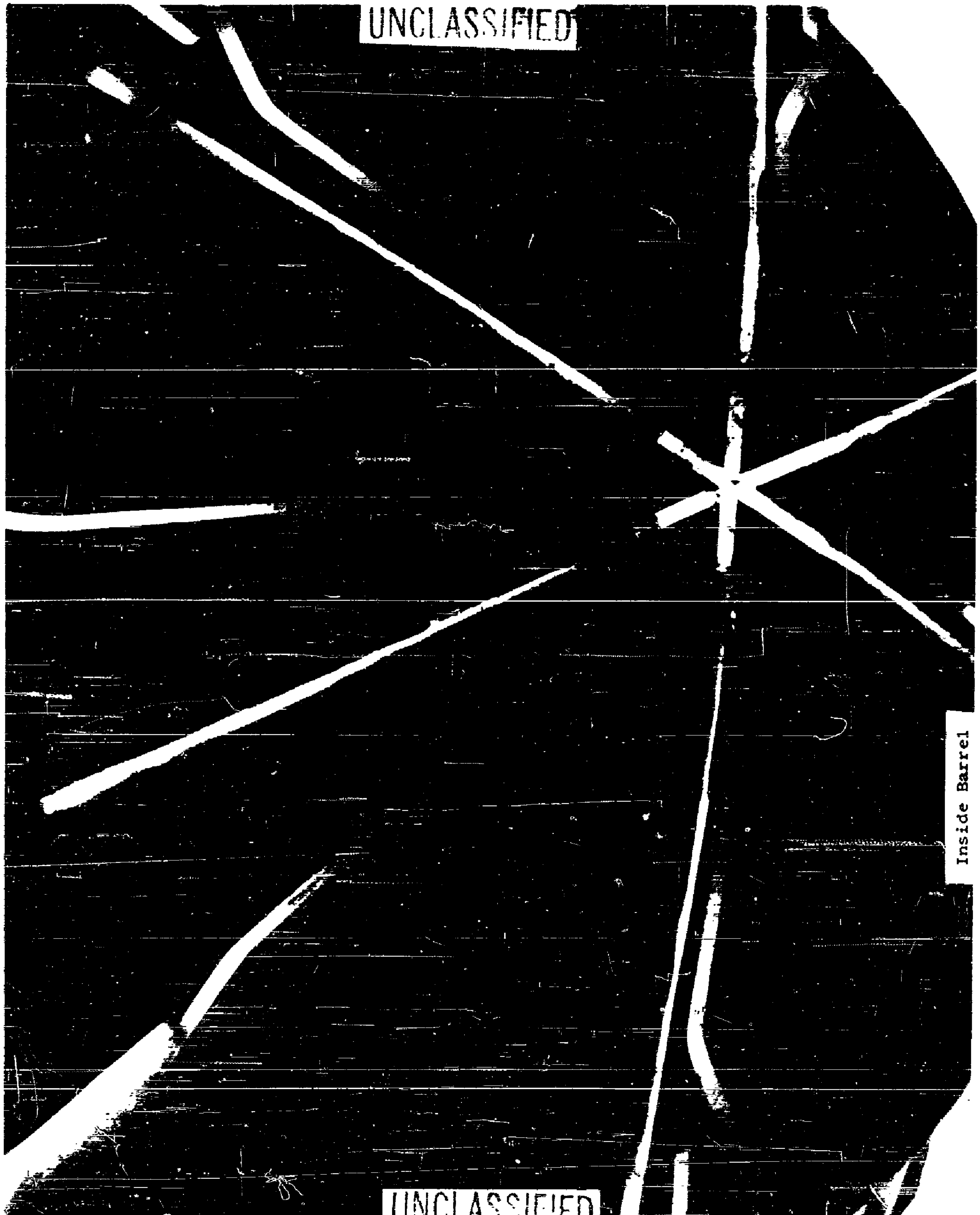
Exterior Side Angle, 500 Pound Capacity Production Mixer



Under Deck Plate: Hydraulic Motor, Speed Reducer, Coupling, Shaft from Which Barrel is Cantilevered and Bearings

Front Looking Into Barrel

Close-up Arrangement of Baffles Visible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Inside Barrel
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The very bright lines on the preceding picture are the finished surfaces of the weldments which hold the barrel together. It was fabricated in six segments and welded together. You will notice a rather massive baffle bisects each of these segments.

These baffles were installed to solve a very important processing problem. They also pose a safety problem that is important. The processing problem they solved was to bring about the proper inter-mixing of the ingredients. They proved to be very effective in this respect. A colorimetric evaluation of the mixing qualities of the baffled barrel mixer as compared with a turbine-blade mixer proved this piece of equipment could achieve a thoroughness of inter-mixing in about five minutes that it would take twenty minutes with a turbine-blade mixer. The baffles lift the material and pour it back upon itself which is very effective.

As stated the baffles also pose a safety problem in that if any baffle becomes loose or if cracks develop in the weld that holds the baffle to the barrel, flexing of the metal within the crack could generate a level of friction which might initiate sensitive materials. That's the reason the baffles are so massive. Their structural integrity must be far beyond question; and to obtain this result, factors of safety are utilized that would make a value engineer grow pale.

The requirement that we must assure the structural integrity of the barrel also resulted in another design peculiarity: the tank-like structure which surrounds the barrel itself. (See photo of front angle of 500 pound capacity production mixer.)

Water for temperature control of the barrel is circulated through this tank portion.

All good design engineers will immediately contend "I can do a much cleaner and neater job of temperature control by water-jacketing the barrel. Why do you utilize a method as crude as this?"

The answer to this question is that water-jacketing requires an inner and outer layer of metal. As I have mentioned, the fact that the welds on this mixer are continually exposed to friction-sensitive ingredients is of concern to us. We want to be able, at intervals, to reassure ourselves as to the structural integrity of these welds. A perfect fusion weld is awfully hard to obtain during fabrication; there are always a few small pits or voids in the root of such welds. We have a very strong desire to monitor the condition of these void areas at intervals--say every six months to a year--to determine if there is any evidence of failures starting at these points.

Fulfilling this desire requires re-X-ray, and it is very difficult to obtain definitive X-rays through two layers of metal. The method of temperature control pictured here is crude but effective, and it does permit X-ray surveillance of potential fatigue points at regular intervals.

Another point of interest is the action of the barrel during operation. During early stages of development on this type of mixing, the barrel was tried at rotational speeds of from ten to fifty rpm. It was found that at approximately thirty rpm the centrifugal force was sufficiently great to cause the material to go completely around with the barrel sections. There was no falling back of the ingredients, and mixing action reached a zero level. The optimum speed for most efficient mixing action was found to be ten to twelve rpm, but this will vary with the viscosity of the material being processed.

Even at rotational speeds as low as ten to twelve rpm, a serious problem is encountered in developing adaptors and transition pieces which will permit remote additionl of ingredients to the barrel and the application of vacuum where such a processing requirement exists. Such adaptors and transition pieces mate a rotating member to a stationary member and friction is usually the result of such mechanical requirements. It is true that very sophistocated airpurge glands or "liquid interface" glands can be developed; however, these devices may not "fail safe."

A more acceptable and simple solution to this problem is now under study. And that is the substitution of a rocking or oscillating motion to the barrel instead of a rotating motion. The degrees through which the barrel may oscillate and still provide good mixing action is a variable that must be examined in relation to the viscosity of the material being mixed. We anticipate the use of approximately 270° of movement.

Hydraulic power is used to motivate the barrel, and the entire power transfer system is enclosed in the covered compartment. If desired, this compartment may be air-purged to give further assurance against exposure to friction-sensitive materials.

After the processing cycle is completed, material is removed from the barrel by either vacuum or pressure, or a combination of the two, depending again upon viscosity. It is obvious a system of mechanical dumping could be utilized; however, such a system would introduce more power equipment, more friction and impact potentials, and more and bigger pieces of metal that would add to the lethal quality of the fragment pattern in case of an explosion in the mixer.

Cleaning of the barrel is accomplished by charging it with the proper solvent and rotating until the mix residue is in suspension; then remove the contaminated liquid by vacuum for disposal at a burning ground. There is a residue of material left on the interior surfaces which must be wiped off by hand, using rags or paper towels.

In summary, it can be pointed out that the barrel-type mixer, with no internal agitator, no submerged glands, and with a gentle but effective mixing action for viscosities below 200,000 centipoise, is safe for the processing of friction-sensitive formulas. However, it should be repeated again, that:

No propellant mixer is sufficiently versatile -- and safe -- that it can be considered a completely universal propellant mixer.

Mr. Niederman: You left out one vertical mixer that Atlantic Research is making. I hate to advertise, but we have a different type of mixer which uses two blades that inter-mesh like a Mixmaster and so you don't get the kind of shearing action you get with the other vertical mixers. It is one of the most versatile mixers and would solve one of the problems that was brought up in the previous paper about short gel time. If you use a vertical mixer instead of a horizontal, you don't have any problems with gel in the mixer because you get them out of the mixer in a short enough time to avoid the gelling. One other comment about the barrel mixers. I would like to point out that you did say they were for very low viscosity mixes. The great majority of mixes being made today are relatively high viscosity and this would not be applicable to the great majority of mixers being made today.

Mr. Settles: Mr. Niederman, I have talked with some of your folks about the mixers you have and its impressive. I don't want to depreciate any part of it and it has advantages over existing internal agitator mixers when you certainly cannot take exception to them. However, we are looking for Utopia. We wanted to get that internal agitator out of there completely because, and you folks know this as well as I do, you have nuts and bolts inadvertently dropping into your mixer, the clearance between the agitator and the bowl gets to be real important. If that foreign material is bigger than that clearance, even tho it isn't, you have a real potential for initiation to occur. So we were looking for something a step further than you folks have gone but I give you full credit for the design work you've done, I think it's good. It's been described to me. I haven't seen it.

Mr. Saffian: The last slide that you showed looked like approximately 90^{o} of that bowl was submerged in water, is that a fair estimate?

Mr. Settles: That's a fair estimate.

Mr. Saffian: It seems to me that in dealing with materials that have high exotherms wouldn't you expect quite a temperature gradient between the material at the top of the ball in any position and the material in the portion under water?

Mr. Settles: Yes, the way you described it, Leon, I would. If it has a high exotherm you've got a problem and you say, well under those conditions I'm sure you would do what we did not do but what we might do with the next one and that is use a water jet.

Mr. Bishoff: Mr. Settles, you gave a very thorough presentation, I enjoyed it. On the turbine mixer, I noticed that the drife shaft was quite long and fairly small diameter and you indicated that there was a very low clearance between the turbine blades and the bowl interior. Is there any whipping action on that drive shaft?

Mr. Settles: I didn't communicate well. The clearance between the blades and the bowl is large as compared with other mixers. It isn't close at all. Maybe as much as 2 or 3". However, the parts alignment is very good and it is something you have to be deeply concerned with in a turbine blade mixer and that is the whipping, the blade is extended out on the end. It's kind of out on the end of a long rod. You have to over-design, you have to have a much greater agitator rod than you would normally require just for strength of material.

Mr. Bishoff: My second question is - on both the turbine mixer and the barrel mixer, there was no cover indicated. Have you considered use of a cover?

Mr. Settles: Yes, we do use a cover on both of them. On the turbine mixer, you could see the cover in the picture, I didn't point it out, but there is a cover that fits over top. On the turbine mixer we use a cellulose acetate again striving for frangible material. On the barrel mixer there is a mating piece that comes in and covers that opening and this mating piece has receptacles in it for dry ingredient incorporation, for liquid ingredient incorporation, they go right thru that piece thru holes in it.

Mr. Nipp: I'm curious as to what portion of the volume of the barrel mixer does the propellant mix occupy if you use a maximum load?

Mr. Settles: This as I said is a 500 pound capacity mixer. Volume will vary with formula of course but by and large most of the time it doesn't come up more than a third of the way in the barrel. Obviously you don't want to get too close to that lip and its also obvious that this thing need not be positioned on some certain slope. You might have it completely level, that is the drive shaft completely level or you might have it more vertical. These parameters we haven't fully explored yet.

Mr. Nolan: An interesting process is perhaps the inert diluent process whereby your individual ingredients are suspended in a so-called inert carrier. Streams of these slurries converge and purely by turbulance accomplish mixing. Then your propellant in turn goes into the motor in which your carrier is decanted and deaeration of your propellant.

Mr. Settles: I know all about the inert diluent process and this again is reaching for utopia. I sure hope it proves out all right. There are problems. We haven't found them all yet.

Mr. Markwood: How do you unload the barrel type mixer?

Mr. Settles: As I said, we have been using vacuum and pressure - one or the other or a combination thereof. You run a hose down into the ingredients, you apply pressure to the top of the mass, you suck on the hose and low and behold it comes out. This barrel is a pressure vessel.

Mr. Jezek: On this water that you use as a coolant, do you find that any of the propellant or the mix may contaminate that water and if it does, do you have any special precautions for pumping and recirculating this water?

Mr. Settles: We don't recirculate although we may later and yes, the potential for contamination is related to spillage and it can happen. You have the human element to contend with. They are going to spill it sometimes. There is one thing in our favor and that is if you do spill stuff in there, you've got a tremendous mass of water around it. Right now we just rotate the barrel in it and at intervals drain it out so it doesn't constitute a real hazard. If we ever start recirculating then you have to be more alert to what's going on.

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SAFETY CONSIDERATIONS OF THE LARGE VERTICAL MIXER IN SOLID PROPELLANT PROCESSING

by
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Solid Rocket Division
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The most notable advance in the safety of large scale batch mixing of composite solid propellants has been the introduction of the vertical mixer. Although many safety advantages are inherent in this type mixer, elimination of the submerged packing gland is by far the most notable single advancement.

Horizontal mixers generally in use in the solid propellant industry were not specifically designed for mixing materials such as castable composite solid propellants, as the mixer and the blade designs were intended for use with materials of much higher viscosity. The blade shafts extend horizontally through the sides of the mixer bowl and through packing glands which are exposed to contamination by the material being mixed. Since blade removal from horizontal mixers is a major maintenance operation, mixer bowls must be cleaned with the blades in place. Obviously this complicates cleanup.

In vertical mixers, on the other hand, blades and mixing action have been designed to meet the needs of the solid propellant industry. There are no submerged packing glands, the mixer bowl is easily removed from the mixer blades, and the bowl can be cleaned at a site specifically designed for the decontamination of equipment. Other advantages of vertical mixers not directly related to safety considerations are a reduction of the mixing cycle time, variable batch size, and more efficient mixing action.

The fact that major mixer manufacturers worked with the propellant industry at the time the vertical mixer was being designed for solid propellant mixing, resulted in the incorporation of various additional safety considerations. Included were such items as nonmetallic contact surfaces, use of mechanical shaft seals and magnetically held covers, mechanical locks for holding the mixing bowl in the raised position while maintenance and check-out is performed, pressure relief ports, adaptability of the mixer for remote addition of ingredients and the absence of "difficult to clean areas." These items were combined to provide a vertical propellant mixer with a high degree of built-in safety.

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In February 1963, a 300-gallon vertical Baker-Perkins mixer was put into castable propellant mixing service at Rocketdyne's McGregor, Texas, facility. This marked the successful completion of an 8-month program of installation, safety evaluation, modification and shake-down to put the mixer into production operations with a high degree of confidence in its safety and processing efficiency. To date, 50 mixes, varying in batch size from 1500 to 4400 pounds, have been processed in this mixer without difficulty. Acceptance of the vertical mixer has been enthusiastic by operating, maintenance, and safety personnel.

Upon completion of the fabrication of the mixer in July 1962, Rocketdyne engineers traveled to Baker-Perkins' plant in Saginaw, Michigan, for inspection and preliminary shake-down. After the brief shake-down was completed and shop adjustments made, the mixer was found to be acceptable. It was then disassembled and shipped to McGregor for installation.

Prior to and during installation, safety information concerning vertical mixers was acquired from other companies engaged in propellant manufacturing through interchange of reports and ideas and through personal visits.

Using our experience with a 25-gallon vertical mixer, together with information obtained from others in the solid propellant industry, a comprehensive shakedown plan was designed to evaluate our 300-gallon mixer installation and to prove the equipment safe and functionally acceptable. The shake-down program was intended to give positive indication of features of the mixer that needed to be re-designed or modified.

Shake-down of the installed vertical mixer was to consist of a dry-run check of all mechanical functions of the machine, determination of operating characteristics of the mixer, mixing of a maximum size batch of "inert" propellant, and endurance mixing of the "inert" propellant. Shake-down operations took place in November 1962.

Early in the shake-down program, it became obvious that there was misalignment between the mixer bowl and mixer head. Mixer manufacturer's representatives were called in and the misalignment was corrected. Since minimum blade-to-blade and blade-to-bowl clearances were set at 0.250 inches, alignment of the bowl and head must be precise to avoid metal-to-metal contact.

Through the dry-run portion of the mixer shake-down, all components of the mixer performed satisfactorily. During the 24 hours of continuous operation, the maximum temperature of the mixer housing

was 134° F. Changes in critical clearances in the mixer bowl were measured as operating conditions were simulated and it was found that the bowl bottom deflected 0.008 inches upward as vacuum was applied, the bowl walls did not deflect under vacuum, and the bowl wall moved outward 0.015 inches as the jacket water temperature was increased 100° F.

A 4400-lb mix of inert propellant was then mixed and the mixer found to be satisfactory. The "inert" propellant consisted of our usual binder-fuel ingredients but sugar and salt were substituted for ammonium perchlorate to simulate the viscosity and density of live propellant.

With the 4400-lb inert mix in the bowl, a 24-hour endurance run of the mixer was started. The mixer was run at high speed for 24 hours to insure that it would operate safely under conditions considerably more severe than those encountered in normal propellant mixing. During this 24-hour run the mixer housing became abnormally hot in the vicinity of the 54-inch cast iron bushing inside of which the planetary housing revolves. After approximately four hours operation, surface temperatures in this area increased to 192° F. and the machine made loud screeching noises. Despite proper lubrication, the cast iron bushing had galled severely where it contacted the stainless steel planetary housing. Again mixer manufacturer's representatives were called and the cast iron bushing was replaced. In addition, the planetary housing wearing surface was chrome plated to prevent re-occurrence of the malfunction. The malfunction was apparently caused by foreign material in the bearing. With the new bearing installed, the 24-hour endurance run was started over again and successfully completed. The new bearing has given no trouble since its installation.

After the shake-down with dummy propellant the mixer head was disassembled and closely inspected. No dust or other material had leaked past the seals between the head and mixing chamber. There was a slight amount of "oxidizer" dust on the lower part of the double seal around the planetary housing, but this was to be expected.

An important point apparent during the shake-down run was the excellent product temperature control possible with this vertical mixer. In the case of our horizontal mixers, a large part of the mixing cycle is used to raise the propellant to optimum casting temperature. With the 300-gallon vertical mixer, the intense mixing action imparts a significant amount of heat to the product. With the mixer running at high speed, product temperature is maintained at 170° F. by circulating 105° F. water through the jacket of the mix can. Propellant ingredients are not pre-heated before being charged to the mixer.

One problem remaining unresolved at this time is that of remotely obtaining accurate product temperature. Our mix can is equipped with a single thermocouple, which is located in the side of the can, approximately 15 inches from the bottom. This thermocouple is affected by jacket water even though it is apparently well insulated from the jacket. At the present time, we are able to operate within process temperature limits by periodically stopping the mixer and verifying the propellant temperature with a thermometer.

Process-wise, the shake-down proved the mixer to be highly satisfactory for propellant processing; however, several safety considerations remained to be resolved. During the shake-down, it became evident that the magnetically attached blow-out port covers were not satisfactory, as these covers became loose during the mixing cycle due to pressure changes in the bowl. To correct this, the magnetic devices for retaining the blow-out covers were redesigned and replaced by mechanically attached covers which relieve at a pressure of 2.5 psi. The tape-controlled, double cylinder hydraulic system provided by Baker-Perkins for lowering and raising the bowl has proved entirely satisfactory. This tape system observes the travel of each piston and should one piston travel at a rate in excess of its companion, the tape activates a compensating valve which automatically equalizes the rate of piston travel. As a redundant safety control, micro switches were installed to stop the mixer should the syncronizing tape fail. Similarly, limit switches were installed to prevent raising the bowl if it became cocked, and to prevent starting the mixer if the bowl were misaligned in the raised position. Further, a hydraulic bleed system was provided to lower the bowl in case of electric power failure to the hydraulic system normally used for this purpose.

To preclude the possibility of extraneous materials getting into the mixer, all fasteners in the building and on and about the mixer were positively locked in place by tack welding or by the use of "Loc-Tite." Screens were also strategically located above the mix can to prevent the entry of foreign materials during those times when the mixer can is uncovered.

All inert ingredients are safety screened or filtered when they are charged to the mix can and the can is covered and sealed for transport to the mixing building. It is subsequently opened only at the mixer at the start of the mixing cycle. Oxidizer is safety screened at the time of its preparation and again when it is remotely charged to the mixer through two vibrating screens as added precaution against foreign materials. All screens and filters used are of smaller mesh than the minimum mixer blade clearances.

Basic process steps associated with the 300-gallon vertical mixer are as follows.

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Mix Building

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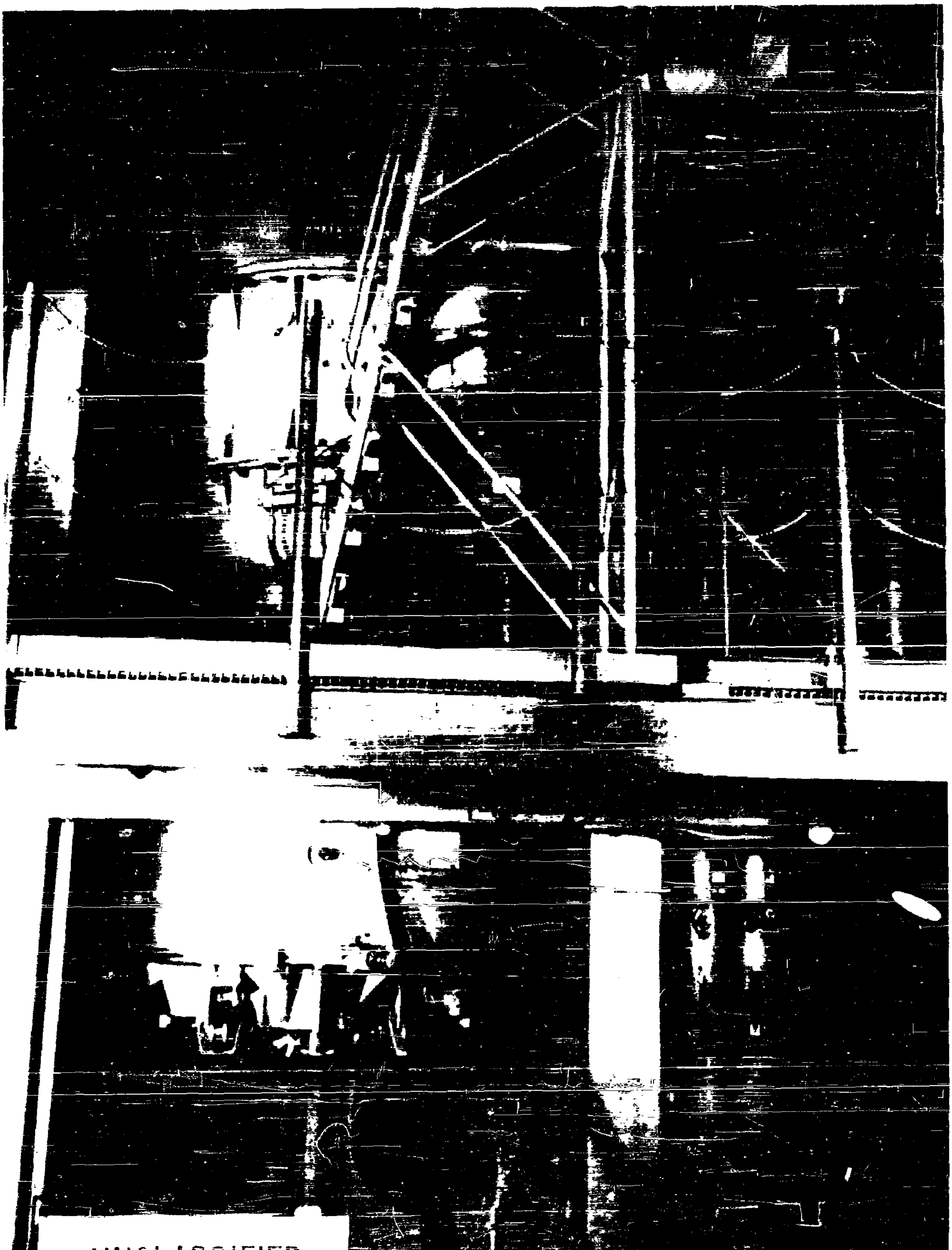

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Overall Mixer Arrangement

Oxidizer Tote Bin on Transfer Cart - The various fractions of oxidizer for a complete mix are weighed into a tote bin and transferred to the mixer as you see here.

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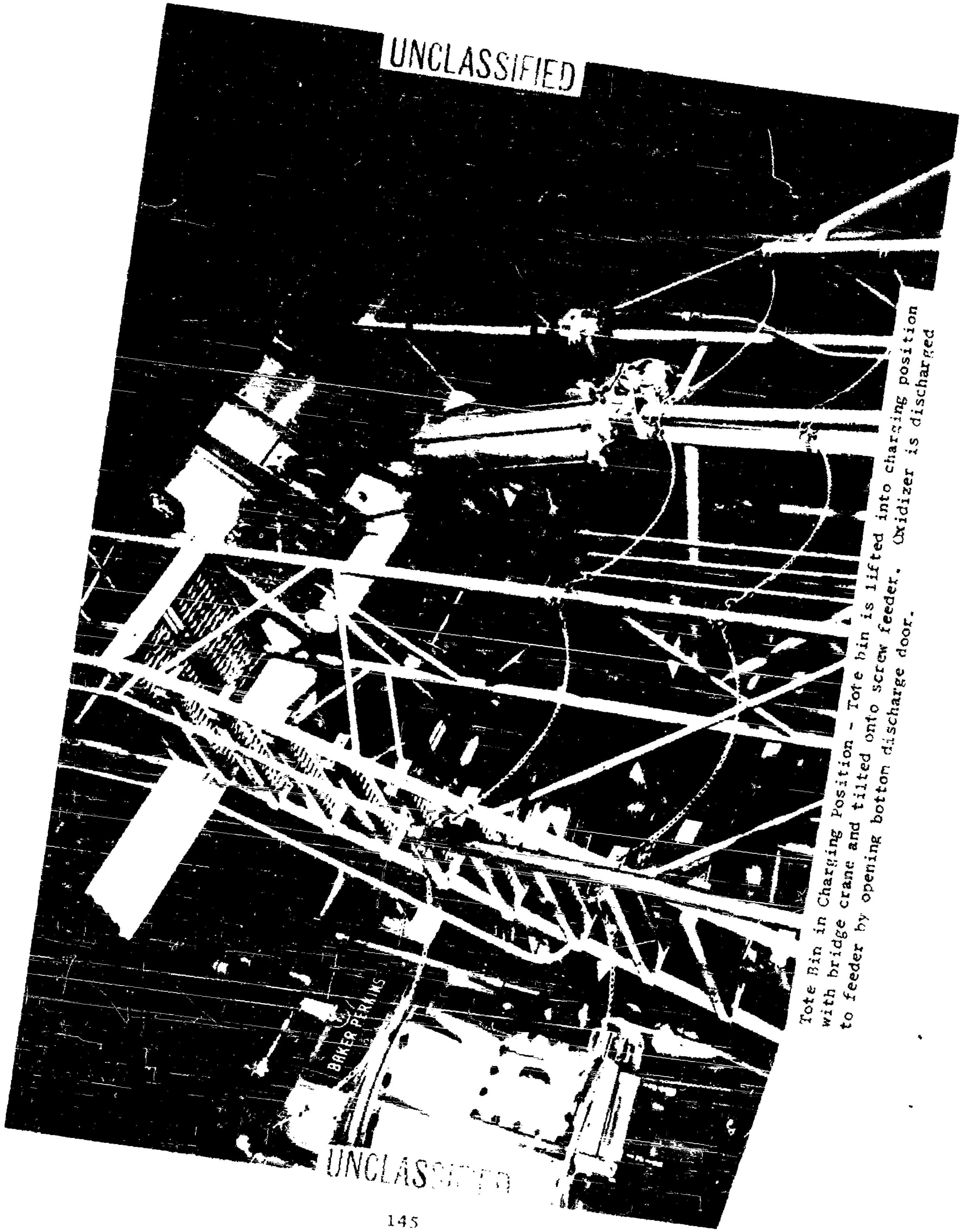

Tote Bin in Charging Position - Tote bin is lifted into charging position with bridge crane and tilted onto screw feeder. Oxidizer is discharged to feeder by opening bottom discharge door.

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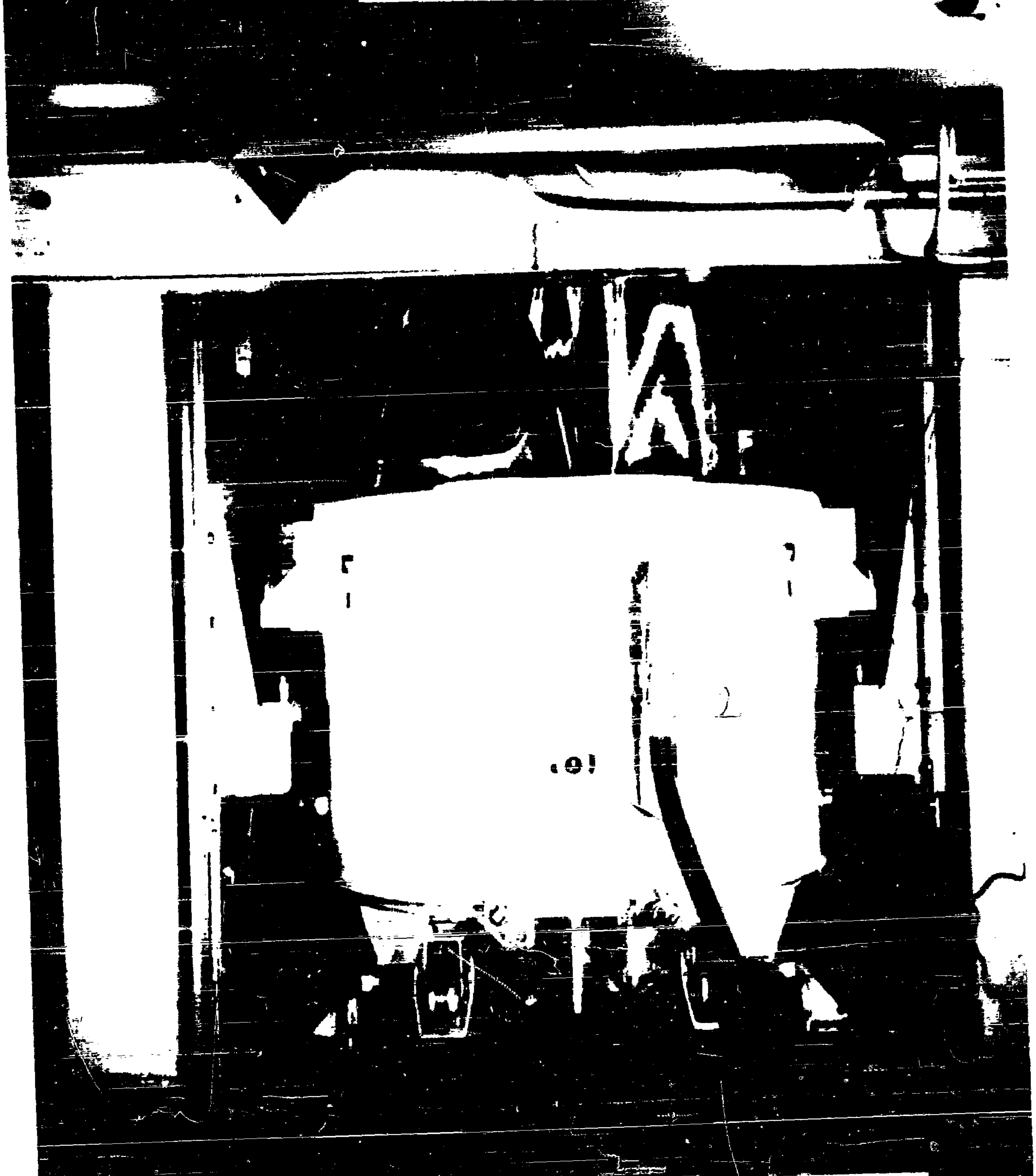

Mix Can Under Mixer - Slurry is transferred to mixer directly in mix bowl and raised to mixing position.

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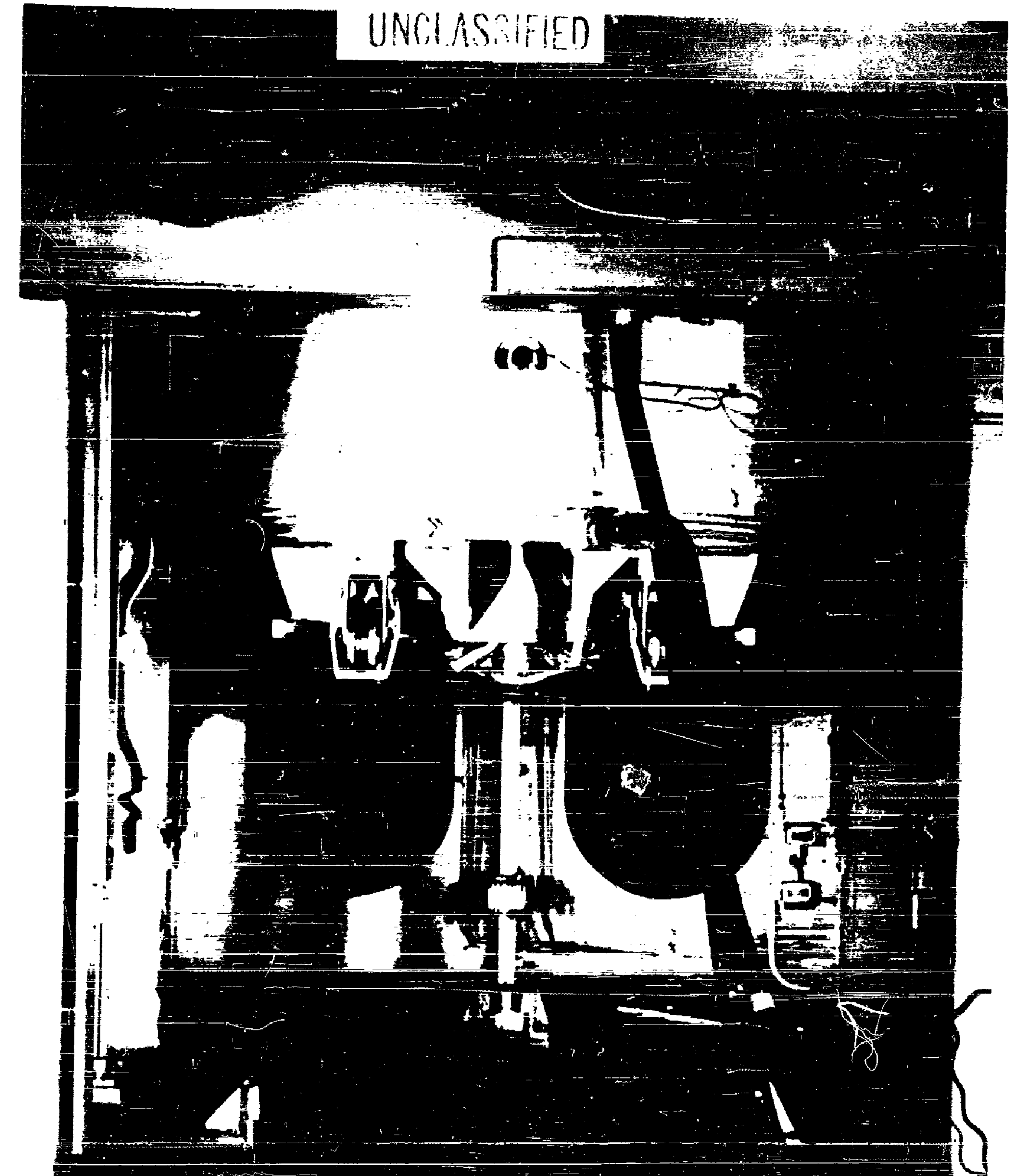
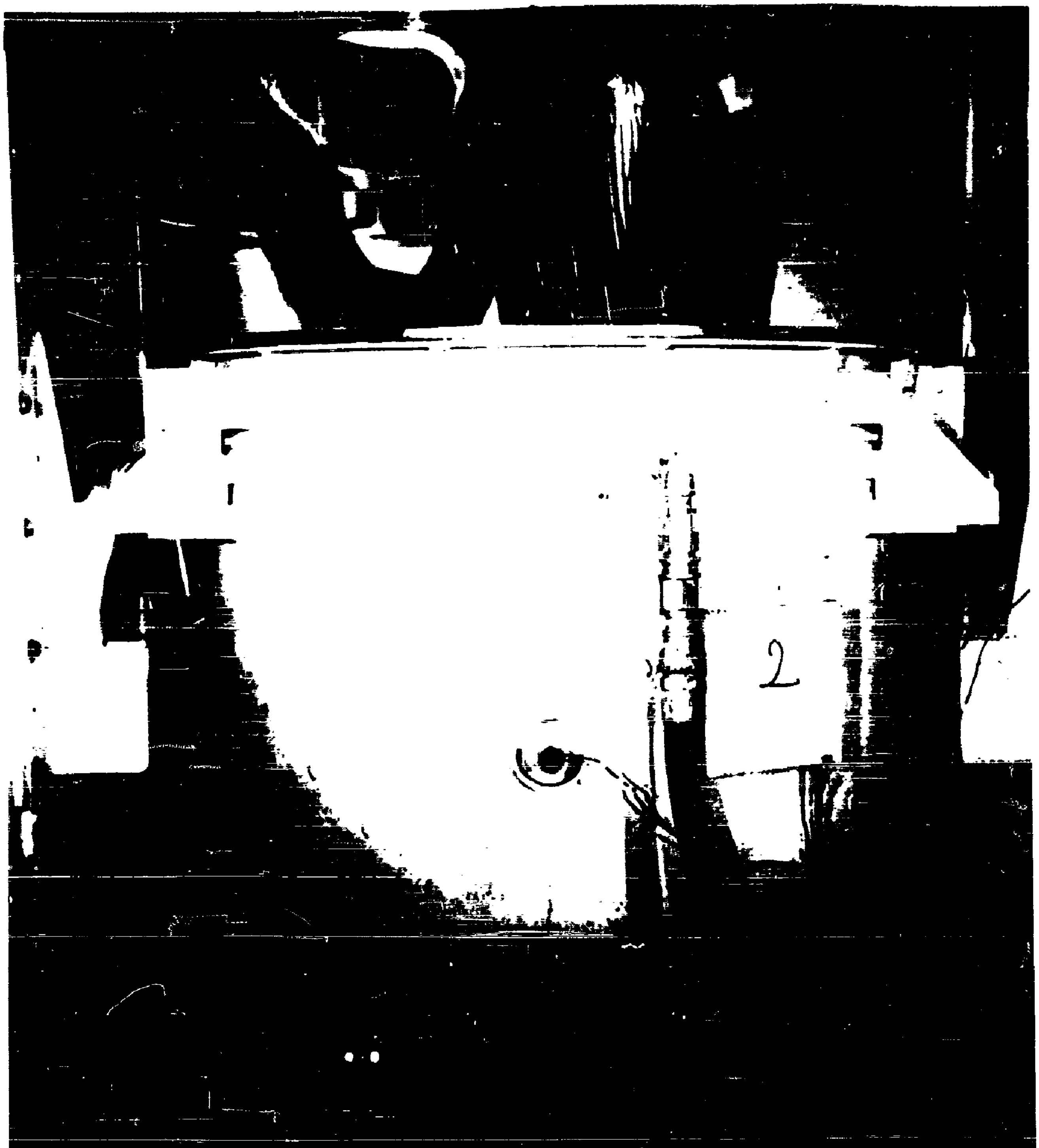


Mix Can in UP Position - After slurry has reached process temperature, oxidizer feeder is remotely engaged and oxidizer is incorporated into propellant while mixer is running.



Mix Can Down Showing Propellant on Blades - At completion of mix, mix can is remotely lowered and prepared for casting. This includes positioning the propellant follower and pressure cover on the bowl.

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Mix Can Down Showing Propellant on Blades

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Mix Can on Transfer Cart - Transfer to casting site is accomplished as you see here. The mix can is positioned on the transfer cart using the bridge crane in the mixing building. Lock pins are engaged to secure the mix can to the transfer cart and assembly is towed to the casting location using a gasoline tow tractor.

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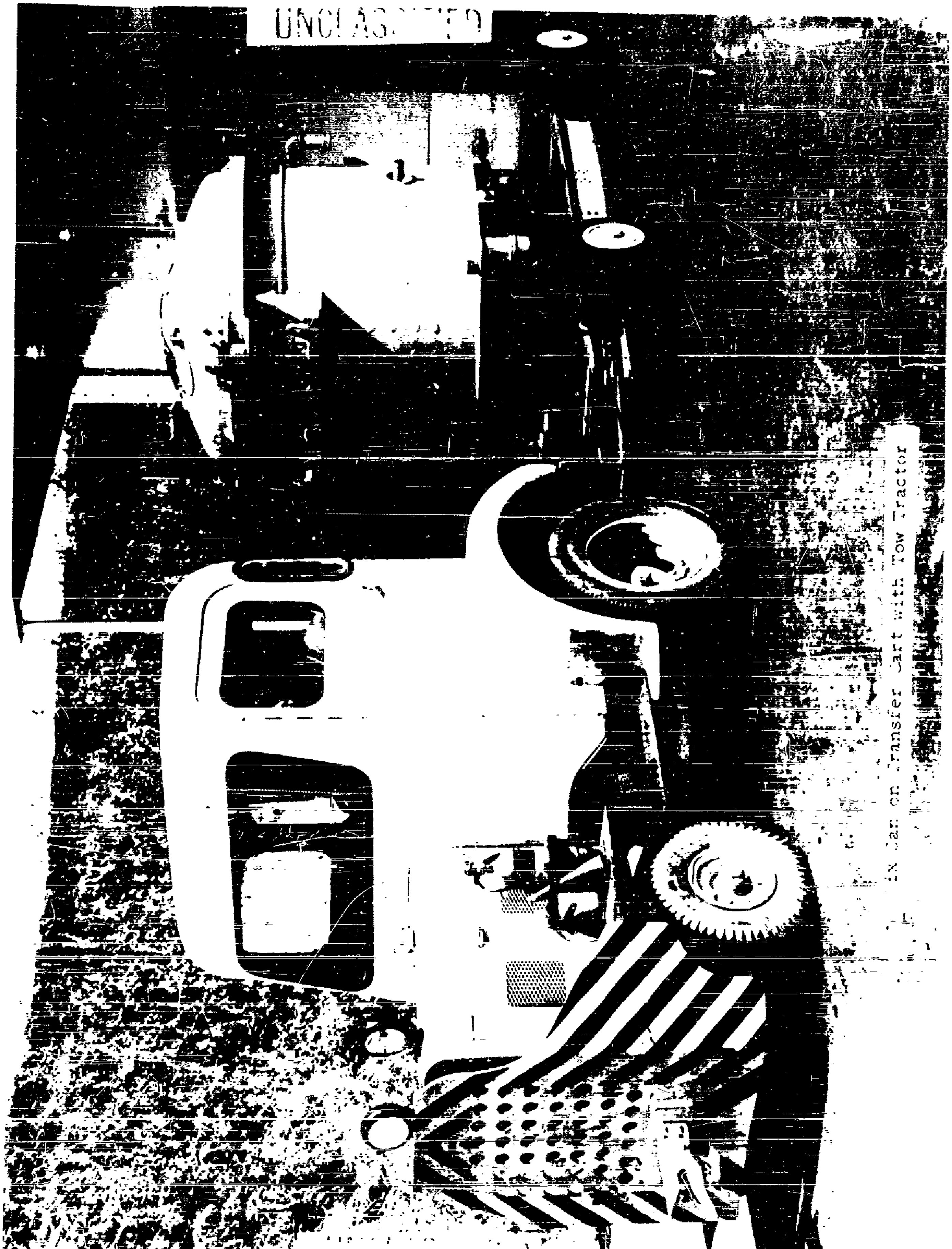

X Can on Transfer Cart with Tow Tractor

Based upon our experience at Rocketdyne together with information received from others in the solid propellant industry, we are convinced that the vertical mixer has significant safety advantages for the mixing of high energy composite solid propellants. The primary advantage being the elimination of submerged packing glands.

THE PROCESSING of EXPLOSIVE PROPELLANT INGREDIENTS *

by

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The Redstone Arsenal Research Division of the Rohm & Haas Company is concerned with the evaluation of novel propellant formulations. In some instances the synthesis of a propellant ingredient candidate has been demonstrated only at the one gram level by our synthetic chemistry group. Such compounds are not commercially available on any scale and must be synthesized within the Division. Many of the compounds are explosive; therefore, synthesis operations involving quantities exceeding five grams frequently must be done remotely. Usually the initial characterization of the reaction and its products is done in batch reactions involving 5 - 200 gms, and successful compounds are next scaled in the pilot plant to production rates up to two pounds per day. This paper describes some of the techniques used in this preliminary pilot plant development, the scale intermediate to that required to support a one hundred pound demonstration motor program.

This particular stage of scale-up is unique in the respect that explosions are fairly frequent, as they are in laboratory development, but the design must provide for economic restoration of the equipment and facilities

* This work was carried out under contract number DA-01-021 ORD-11878.

after an explosion. Safety is always a primary consideration in any design, and in its name ease of operation must often be compromised. Many of the special techniques used at Rohm & Haas are based upon ideas developed by other agencies. Fortunately there is a free exchange of design philosophy and detail among competitive organizations; this is a unique feature of the industry.

Scale-up Guidelines

At any stage of development all possible sensitivity information is acquired as early as possible to determine the hazards associated with handling and processing. Some tests require amounts which cannot be readily synthesized in the laboratory and are necessarily deferred. Prior to pilot plant scale-up sensitivity tests include thermal stability and impact by both Olin Mathieson and Picatinny machines. All these tests are readily accomplished with only a few grams of product. They provide clues pertaining to the explosive hazard, but (as will be noted later) complete characterization requires collation with all additional tests. Probably the most important sensitivity information is the compound's previous laboratory explosion history; practically all compounds of interest have an explosion history from the laboratory program, and interpretation is usually difficult. For scale-up purpose a definition of the cause and remedy of the explosions is required; ordinarily reactions having a series of unexplained laboratory explosions are considered unacceptable. The distinction is usually based upon previous experience and intuition because the explosive conditions are often too involved to be experimentally duplicated.

Because of the multitude of problems associated with the installation of remote explosive processes, promising novel chemical reactions are often scaled up with prototype compounds before the synthesis of a candidate ingredient has been demonstrated at the one gram level. This technique avoids the need for haste in response to user demand. An acceptable prototype should present the minimum hazard characteristics associated with the particular class of compounds and it must have easily solved handling difficulties. The product

should not be very impact sensitive and should be thermally stable. Synthesis is continued as required for preliminary process development and for further characterization of the product's sensitivity. Although a use is sometimes found for the chosen prototype, this is not a requirement.

Similar criteria are established for the candidate of interest for propellant application. Although usually more sensitive by both impact and thermal experiments than was the prototype, the compound must have a reasonably explosion free laboratory history, such as a series of four or five runs without incident. It is particularly important to avoid scale-up of a candidate which frequently explodes, because the cost in dollars and time of repair on the larger scale would preclude the very propellant development program which justifies the ingredient scale-up.

Toxicity is another early concern. So far, tests have been confined to the difluoramino compounds and derivatives of decaborane. Only acute testing has been attempted and it is intended to determine only the generalized toxicity hazard of each compound. Although every attempt is made to avoid ingestion, additional precautions would be required for an extremely toxic material. The lethal oral dose is determined by force feeding white rats the test mixtures diluted in a compatible, edible solvent such as Wesson Oil. Inhalation tests are made in the toxicity chamber shown in Slide 1 by exposing the rats for periods up to four hours. The test material is continuously metered into the influent air, which is normally adjusted for a complete air change every minute. In both cases the test rats are observed for at least twelve days. In general, the chemically active materials used in explosive work have been found to physiologically active, i. e., toxic to the test animals. However, none so far has proved to be an acute poison.

Process Development

a. Hazard Evaluation - Because only limited sensitivity information is available from laboratory experience.all new liquid pilot plant products are remotely diluted with solvent to at least 50% for desensitization, the level being set so that no fires occur at the limits of the Olin-Mathieson and Picatinny machines. All personnel exposure is considered very cautiously. Direct handling is narrowly

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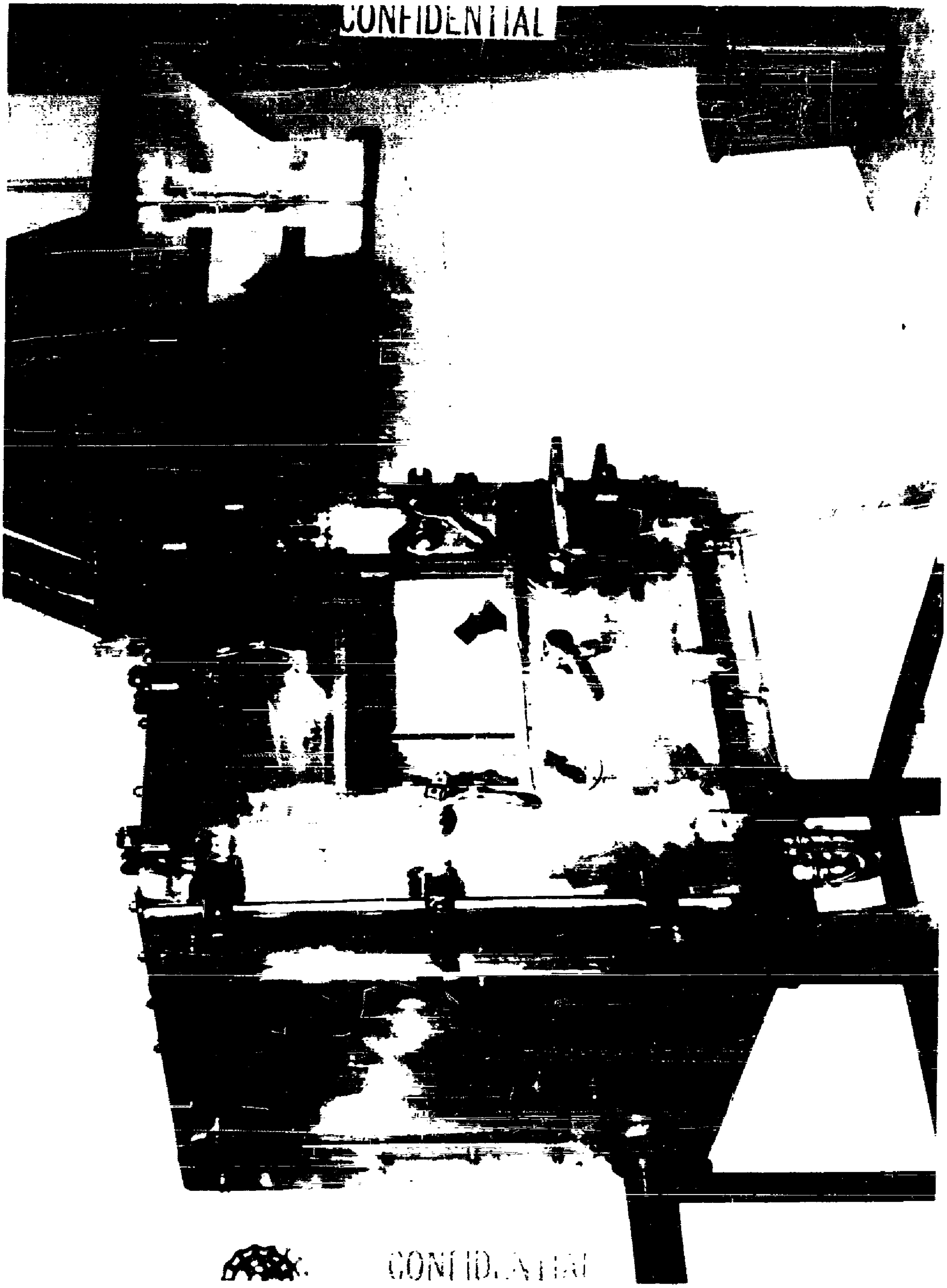

Slide 1

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limited to explosive products at ambient temperature and pressure. Initially the explosive weight per container might be restricted to as little as 25 grams.

Initial batches of the diluted product are subjected to an additional series of hazard characterization tests which are required for confirmation of the laboratory production findings. The next two slides summarize these sensitivity experiments with experimental values for 1,2-bis(difluoramino)-2-methylpropane, a typical product currently being synthesized. The tests listed in Slide 2 are intended to subject the compound to stimuli which might occur during handling. Only derivatives of tetrafluorohydrazine have been tested, and no attempt has been made to standardize the experimental techniques to the point of accurate determination of energy input. None has produced an explosive reaction.

1. The Bottle Drop is intended to describe the effect of impact which might occur during transport. The usual storage container, made of glass, polyethylene, or aluminum, is filled with 10-100 grams of the test material and dropped into a boiler plate reservoir from heights which can be varied from 0-10 feet.
2. The Atlas Match[1] is used to determine if an inadvertent ignition would cause a compound to burn to explosion. A 10-100 gram sample is placed in an open beaker, and the electrically ignited match is located at or below the surface of the sample.
3. The Squib[2] is used to characterize the reaction upon initiation associated with an incandescent mass and some shock. The procedure is the same as that used with the Atlas Match.

Many of the sensitivity experiments serve only to rank the compound in the spectrum of explosives previously tested; these are summarized in Slide 3. The results are meaningful only when interpreted in terms of process experience with previously tested compounds which have similar hazard characteristics. Therefore, it is particularly desirable to have a large background of testing in these areas.

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[1]Atlas Powder Company.

[2]Squib Electric M1A1, Atlas Powder Company.

SLIDE 2

Application Hazard Tests and Findings
for
1, 2-Bis(difluoramino)-2-Methylpropane[1]

Bottle Drop:	No reaction with 100 grams in polyethylene 10 drops
Atlas Match:	60 grams burned quietly in polyethylene
Squib:	60 grams burned quietly in polyethylene

SLIDE 3

Sensitivity Ranking Tests and Data
for
1, 2-Bis(difluoramino)-2-Methylpropane[1]

Processing History:	a. One explosion upon introduction of improperly worked-up product to air b. Reaction mixture exploded upon contact with air
Minimum Diameter:	a. < 0.27" steel b. > 0.47" glass
Card Gap:	37 cards
Picatinny Impact:	No fires at 38 Kg-in.
Olin-Mathieson Impact:	17 Kg-cm (50% fire level)
Differential Thermal Analysis:	Vaporization endotherm at 100°C

[1]Purity >98% by vapor phase chromatography.

1. Processing History, both laboratory and pilot plant, is probably the most important safety criterion, since experience is cumulative and continuously collected. Here the product and its precursors are subjected to a wide variety of conditions.

2. A knowledge of the Minimum Diameter which will sustain a high order detonation in a given pipe material sometimes helps the process designer to minimize damage by using piping sections having a diameter below the critical. The experimental values are obtained by a standard technique.[1]

3. The Card Gap experiment is a relative measurement of the minimum shock required to initiate a high order detonation in a sample. The shock felt by the sample is attenuated by placing cardboard spacers between it and the C-4 donor. As the thickness of the critical gap of spacers or cards increases, the test material is more easily detonated. The experimental values are obtained by a standard statistical technique[2,3].

4. The Picatinny Impact is probably most familiar to the industry and is particularly useful because of the large accumulation of data with it on many solid compounds.

5. Although the Olin-Mathieson Impact test for liquids is similar to the Picatinny Impact, it sometimes errs badly in the non-conservative direction when the explosive contains a volatile component.

6. Thermal Stability is obtained by deferential thermal analysis. In addition, the 22 cartridge[4] technique is used for solids and gels.

After suitable experience many pilot plant products are handled neat to relieve the user of a normally difficult solvent stripping step. Although the option to handle the pure product must be supported by all tests, obviously a preliminary decision is required to handle enough pure material to complete the testing program. This decision is conservatively based upon the laboratory data, large scale tests on the diluted material and process history. Initial quantities handled might start at five grams and, as the findings accumulate, gradually increase to the one quarter pound charge necessary for card gap tests. First tests would include the bottle drop and Atlas Match, because these are probably the most

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[1]Brandon, W. W., Bull. 16 mtg. JANAF Solid Prop., Group V, 109, 1960.
[2]Ibid.
[3]NOTE: This technique predates and is not equivalent to the standard ASESB test described in Bulletin TB700-2.
[4]Booman, K. A., Minutes of the Fourth Explosive Safety Seminar on High Energy Solid Propellants, ASESB, p. 192, 1962.

common forms of initiation to occur during handling. A single positive result would stop the testing program and force continued dilution with solvent. For example, although one major pilot plant material, 2, 3-bis(difluoramino)propyl formate, passed all the preliminary sensitivity criteria, it has never been characterized undiluted beyond the laboratory scale because the pure product fumes in air.

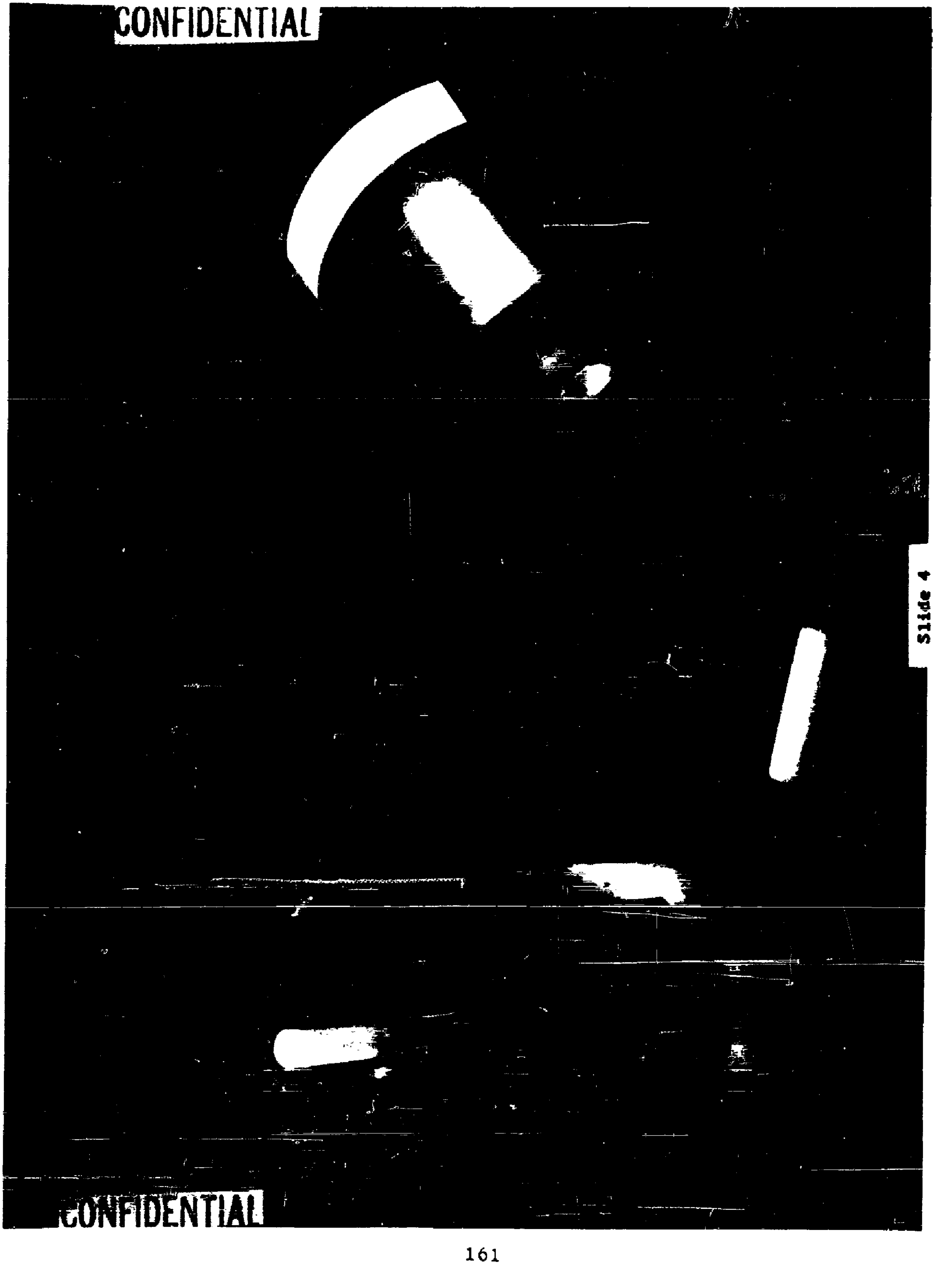
b. Process Control - For complete understanding of any pilot plant process a development program must be conducted to define the effect of each process variable. This is particularly important with explosive processing to further characterize the explosive nature of the reaction and its products as well as to simplify equipment and handling techniques. Throughout at least the first operating year every run involves the change of at least one variable; however, the batch size is minimized for any variable change which would conceivably result in a process fire or explosion. Initial scale-up of a process change is always done in small increments, sometimes beginning with a study of variables in 1/4 ml samples in the pilot plant laboratory. Analysis by vapor phase chromatography and infra-red spectroscopy requires only trace samples, so that major process changes can be tested rapidly and safely on a very small scale prior to pilot plant trials.

Because samples represent a special hazard through direct personnel exposure, analytical procedures have been miniturized so that 1/4 ml is usually adequate for all the required testing. The duPont tote barricade[1] has been modified as shown in Slide 4. The sample container is a Teflon rod with a 1/4" bore, sized to contain the required sample. The initiation propensity of rubbing surfaces has been reduced by stoppering with a tapered Teflon plug. Teflon is preferred to glass which may react with difluoramino compounds.

Equipment

The high probability of explosion in a new pilot plant process restricts the choice of processing equipment to that which can be easily installed and replaced at low cost. Expensive hardware should either be relatively

[1] Swed, J. P., Minutes of the Fourth Explosive Safety Seminar on High Energy Solid Propellants, ASESB, pp. 123, 127, 128, 1962.



Slide 4

indestructibleor should be protected in some manner from a potential explosive source. Visual observation techniques are preferred to the more expensive telemetry equipment which could be destroyed. Whenever possible equipment is located in inert areas to avoid destruction. For example, it an explosive liquid is to be metered very accurately, the preferred technique is to displace it with an inert liquid which is pumped from behind a barricade; in the event of an explosion only the pipeline is lost. Another requirement is the absolute minimization of explosive hold-up in processing equipment, which is a feature not often found in commercially available equipment. Consequently, many items must be designed and fabricated within the Division.

Transfer of liquid explosives is usually by gravity feed or application of vacuum upon the acceptor vessel to avoid the hazard of pumping. Mechanical work on the fluids cannot be avoided in the case of valves, however, so they are usually remotely actuated. Some types of remote valving systems commonly used (Slide 5) are:

1. Right angle gear boxes and steel rods, used for direct actuation of remotely located metering valves or stopcocks. A series of washers is welded to the rod to preclude the possibility of a rod being projected through the barrier and into the control area during an explosion.
2. The Hoke toggle valve, modified for on-off actuation by an air cylinder.
3. Vacuum hoses sealed by clamps operated by an air actuated cylinder.
4. Needle control valves or stopcocks, positioned for throttling by a speedometer cable.

Barricades

Barricading of the reaction area is required to protect operating personnel from the effects of fire, explosion, or detonation. A three sided substantial wall cell is ordinarily used for batch operation such as the synthesis of 2,3-bis(difluoramino)propyl acrylate. Slide 6 shows the operating area associated with such a cell. Visual observation of the reaction area is possible through the use of Plexiglas sight ports. The 12" reinforced concrete walls and 8" thick Plexiglas sight ports will offer protection against a confined detonation involving as much as ten pounds of explosive, but ordinarily less than five pounds

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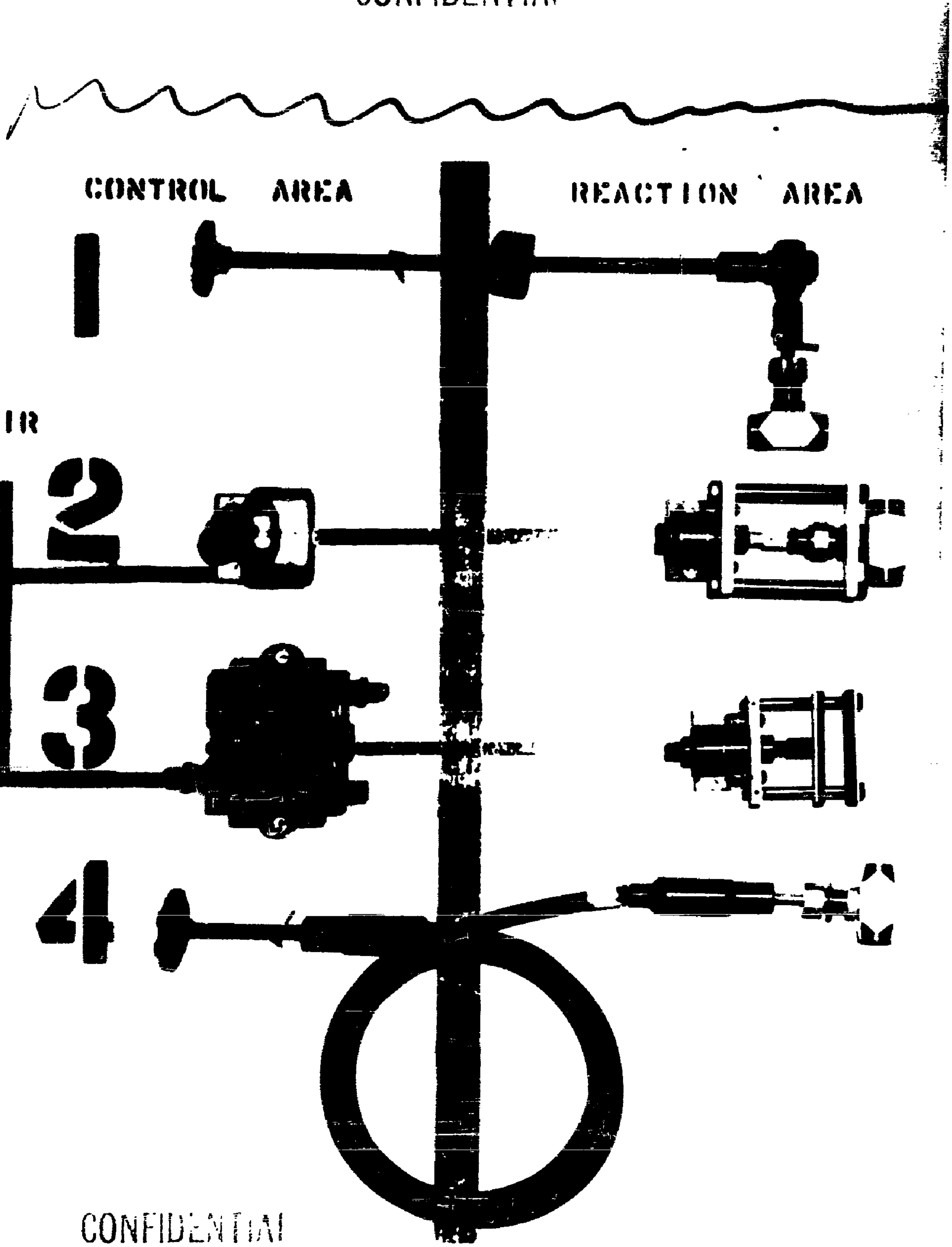

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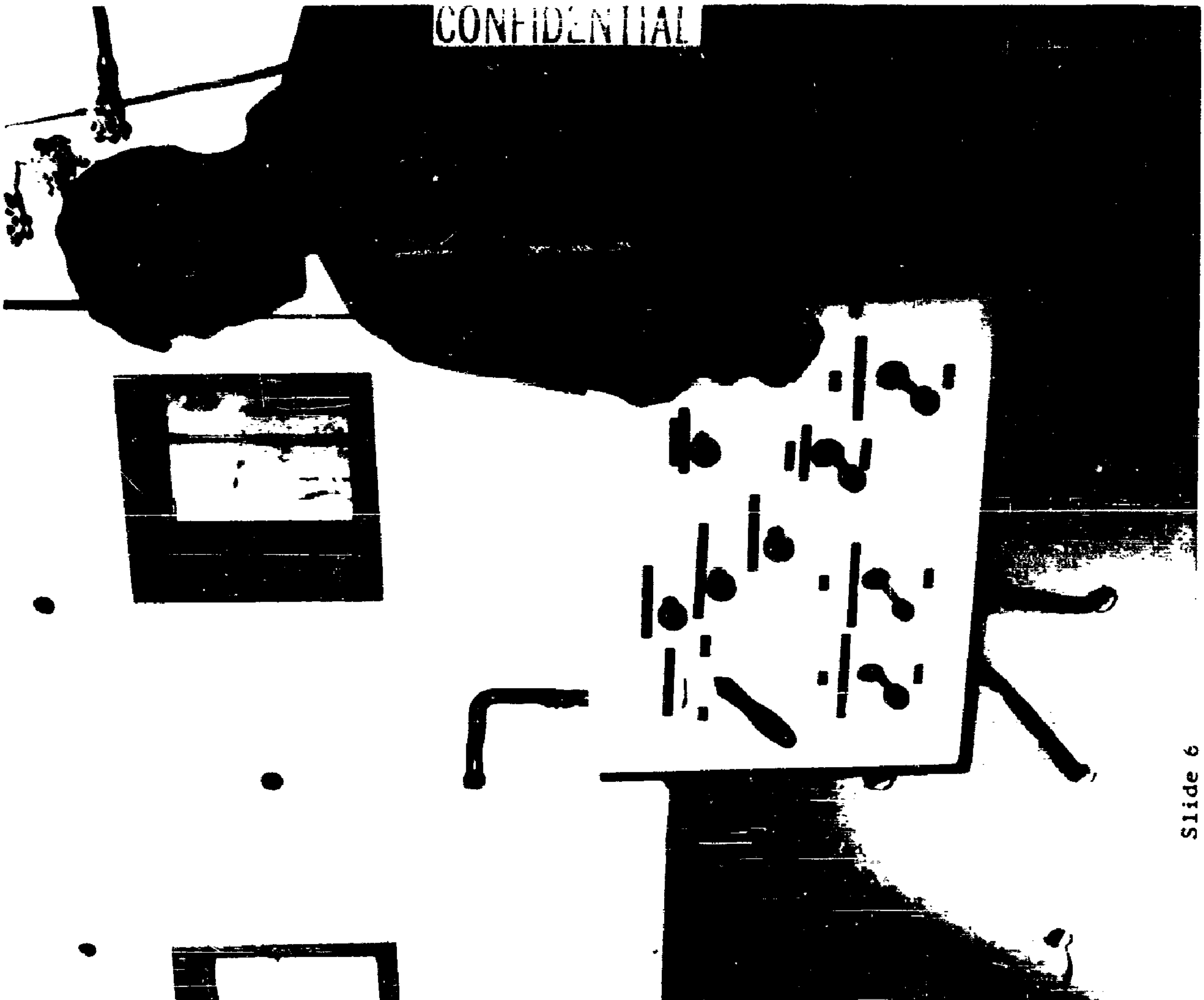
Slide 5



Slide 6

are processed. Venting is through the frangible Fiberglas roof and the rear of the bay. The various holes in the wall are used to run utilities and control lines into the reaction area. Mounted on the board are 4-way air valves used to operate the modified Hoke valves mentioned previously.

The shielding used for continuous reaction with gaseous raw materials is shown schematically in Slide 7. The explosive limit in this unit is 100 grams (located at least 12" from the shield), mostly represented in the usual case by accumulated condensed product. Consequently, the time required for periodic liquid product purification and removal in small increments is the limiting factor in production capability. The production rate is not as severely limited with this shielding for gaseous products, which may be piped through pressure tubing for storage in a heavily shielded area elsewhere. This shield has been used for the synthesis of gases such as tetrafluorohydrazine and liquids such as 1, 2-bis(difluoramino)-2-methylpropane.

The boiler plate shield illustrated was installed in a concrete cell so that the reaction area was enclosed on two sides by 12" reinforced concrete and on two sides by boiler plate extended to the roof line with angle iron reinforced 3/4" plywood for venting. The metal shield was vertically reinforced at three foot intervals with 1-1/4 inch angle iron. The compressive angle iron members attached to the long side were necessary to prevent shifting of the boiler plate from over-pressures associated with slow pressure buildups such as would be found with fires or explosions. The mass of the boiler plate was too heavy for shifting from typical overpressures applied to the short side. The operating area was roofed with wire screening to intercept missiles. As shown in Slide 8, the angle iron reinforced door was retained on each side by four heavy dogs which had a calculated yield strength greater than that of the door. As shown in Slide 9, the advantage in this type of system is that valves, pressure gages, piping, etc. of the gas phase portion of the system can be mounted directly on the panel board and, in case of an explosion, are easily repaired or replaced. However, valves exposed to liquids must be mounted at a distance and operated remotely.

The boiler plate as shown affords no protection against the detonation of a confined charge, because the high velocity primary metal fragments would perforate the shield. However, experiments confirm that adequate protection

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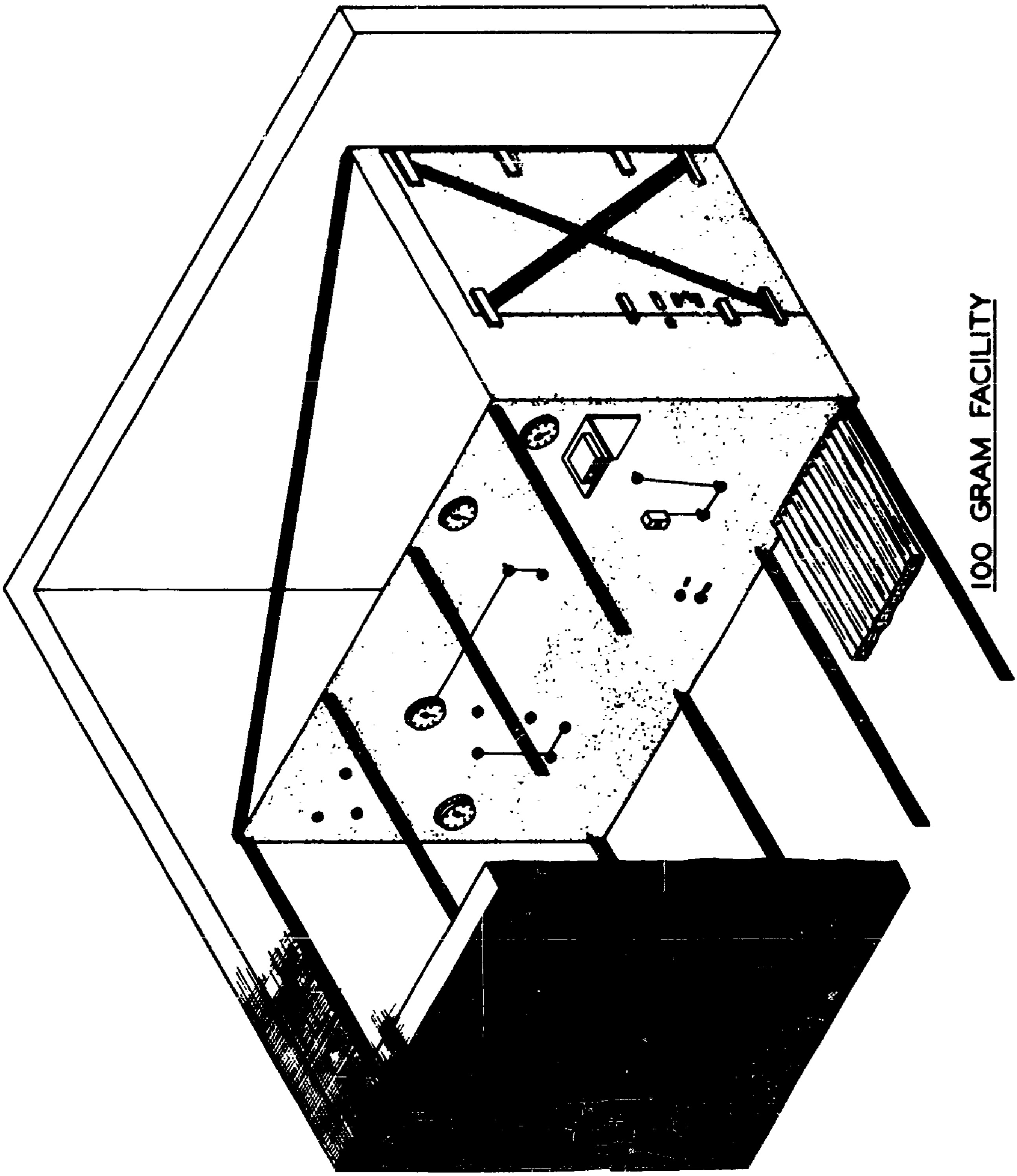

100 GRAM FACILITY

Slide 7

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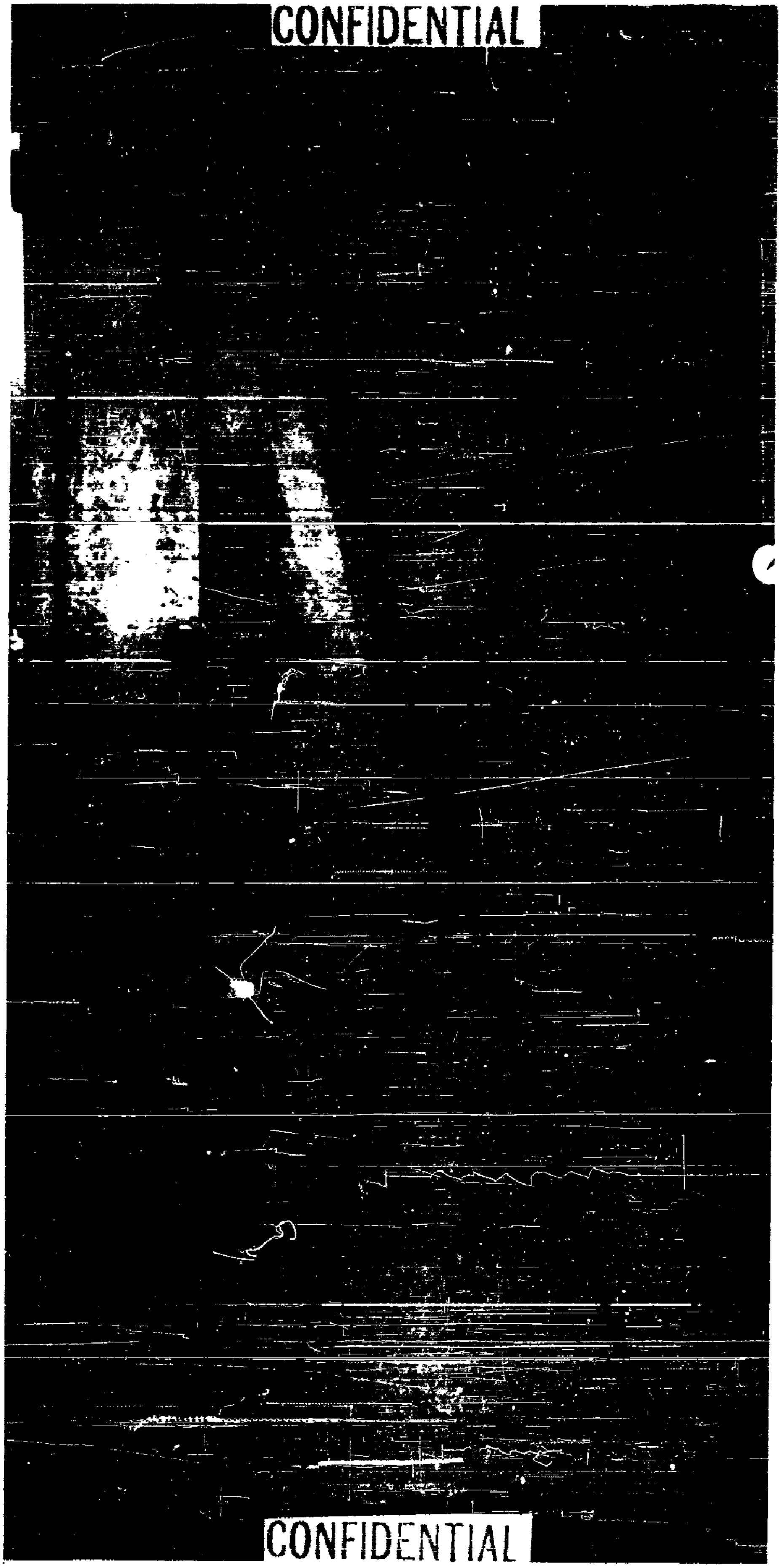

Slide 8

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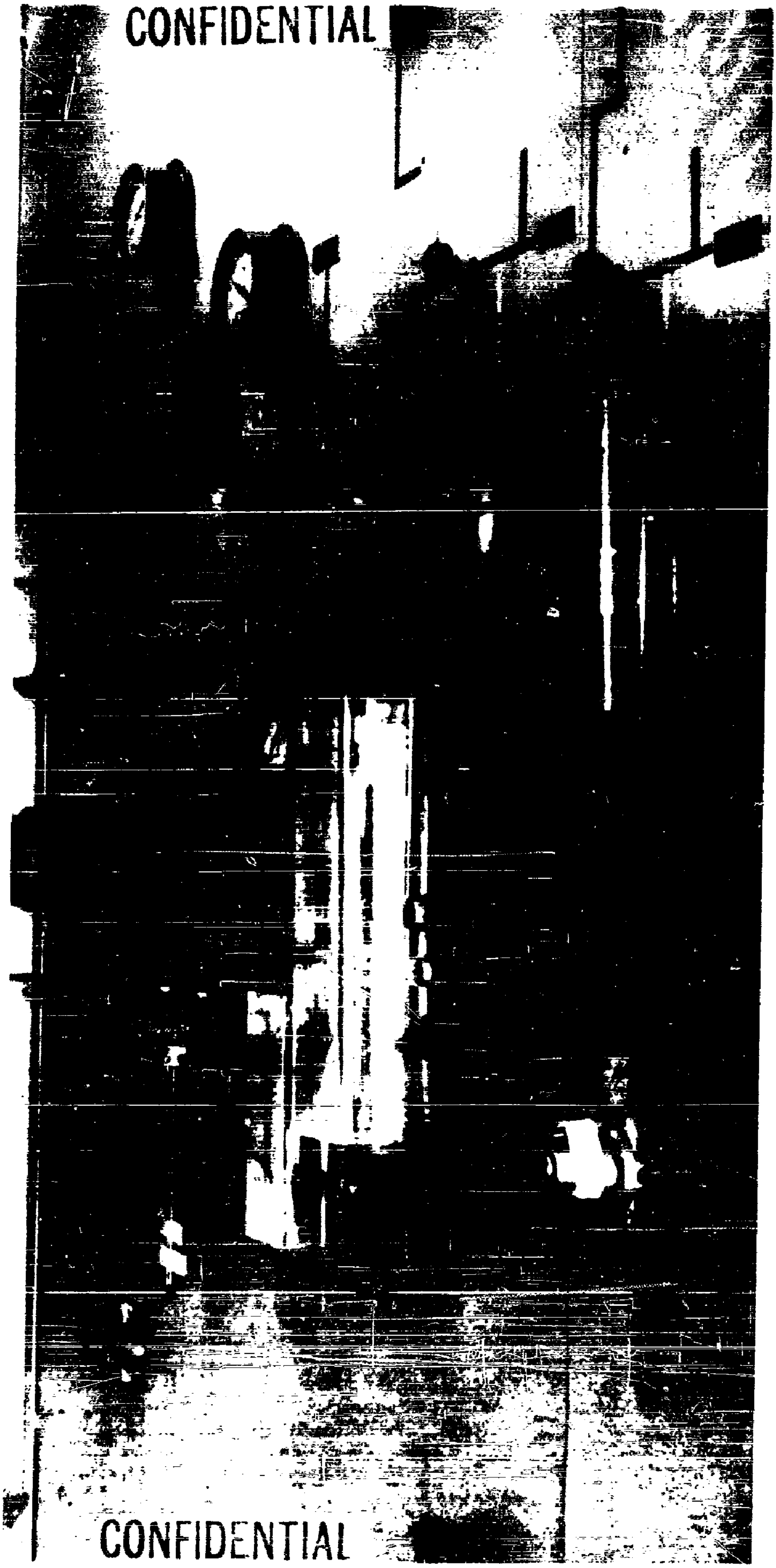

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Slide 9

against missiles is offered by 1/4" boiler plate if a one pound confined detonation occurs centered inside a secondary twelve inch (Schedule 40) water pipe. Slide 10 shows a sacrificial pipe shield of this type.

Although the boiler plate shielding gave protection from shrapnel and flame, the associated noise level was not significantly attenuated. Consequently ear protection[1,2] is required to counter the potential psychological and physical damage from the sound pressure of an explosion. Either ear muffs or ear plugs are acceptable. In addition, safety goggles are required as protection against flame and low velocity hardware.

At least twenty explosive incidents have been experienced with this shielding system with quantities involving 5 to over 200 grams. After each incident the shield was carefully re-evaluated and, if necessary, additional barricade testing was initiated. The shield design described here has been modified quite often through the four year period of use. In one incident the protection of an earlier design was found inadequate when sixty grams of material exploded, vaporizing and igniting an oil heating bath, and producing an overpressure which shifted the boiler plate 17". Following this incident the compressive angle iron members were added, and all fuels such as oil baths were included in the explosive limit calculation. A series of tests indicated that the barricade was effective for the detonation of at least 200 grams of high energy material, but a one pound detonation caused a prototype shield to blow apart at the welded seams.

Explosive Storage

DuPont and Rohm & Haas cooperated in the development of the pipe explosive storage field shown in Slide 11. This system eliminates incompatibility difficulties common to magazine storage. The explosive limit is based upon one pound charge per pipe; consequently, the fifty two pipes could be located immediately adjacent to the operating building. The 4" Schedule 40 water pipes are capped on the bottom and vertically imbedded four feet below ground level on five foot centers. The pipes are lined with polyethylene to reduce the possibility of breakage of glass storage containers.

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[1]Straightaway Ear Protectors, David Clark Company, Worchester, Massachusetts.
[2]Lee Sonic Ear Valves, Sigma Engineering Company, Los Angeles, California.

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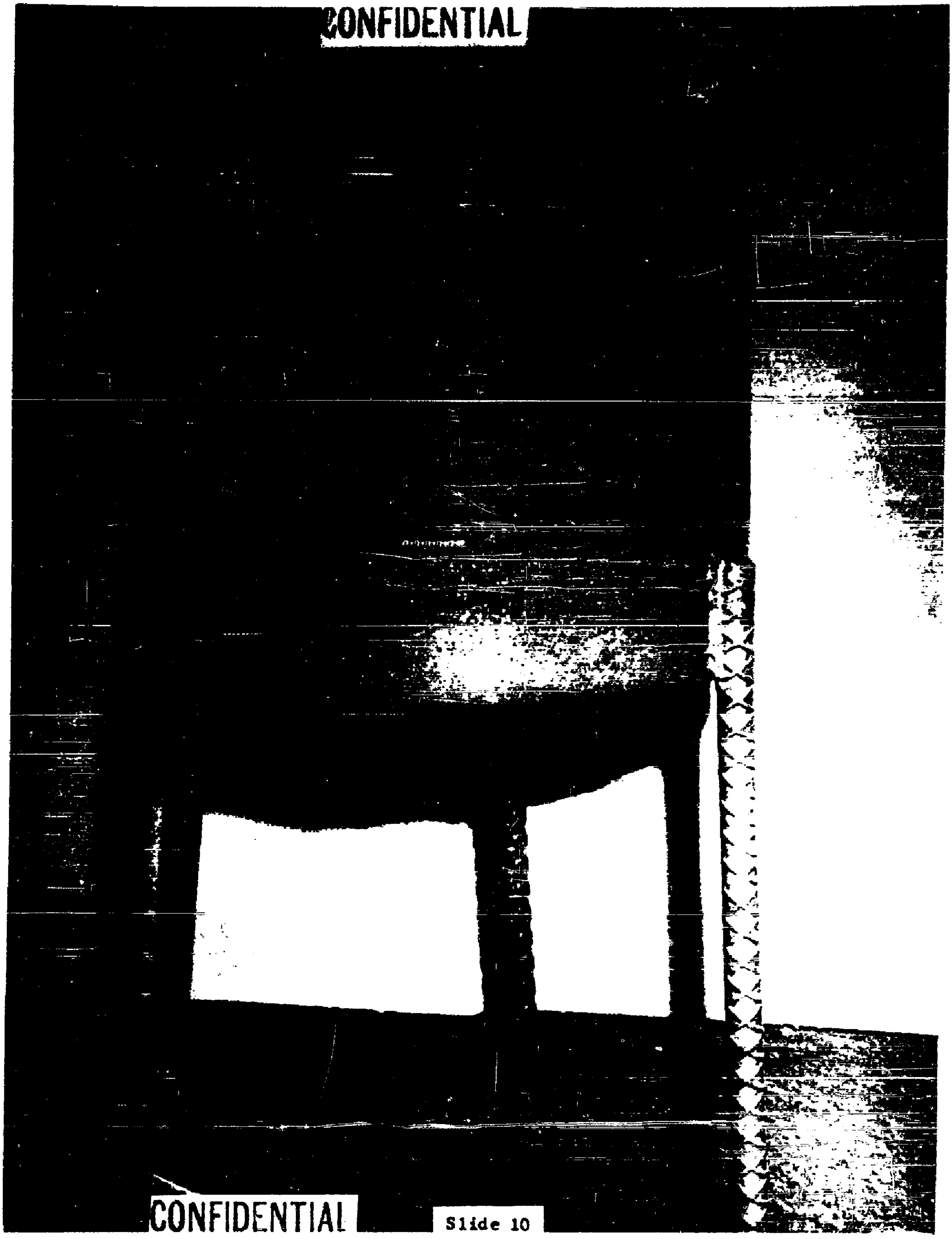

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Slide 10

Slide 11

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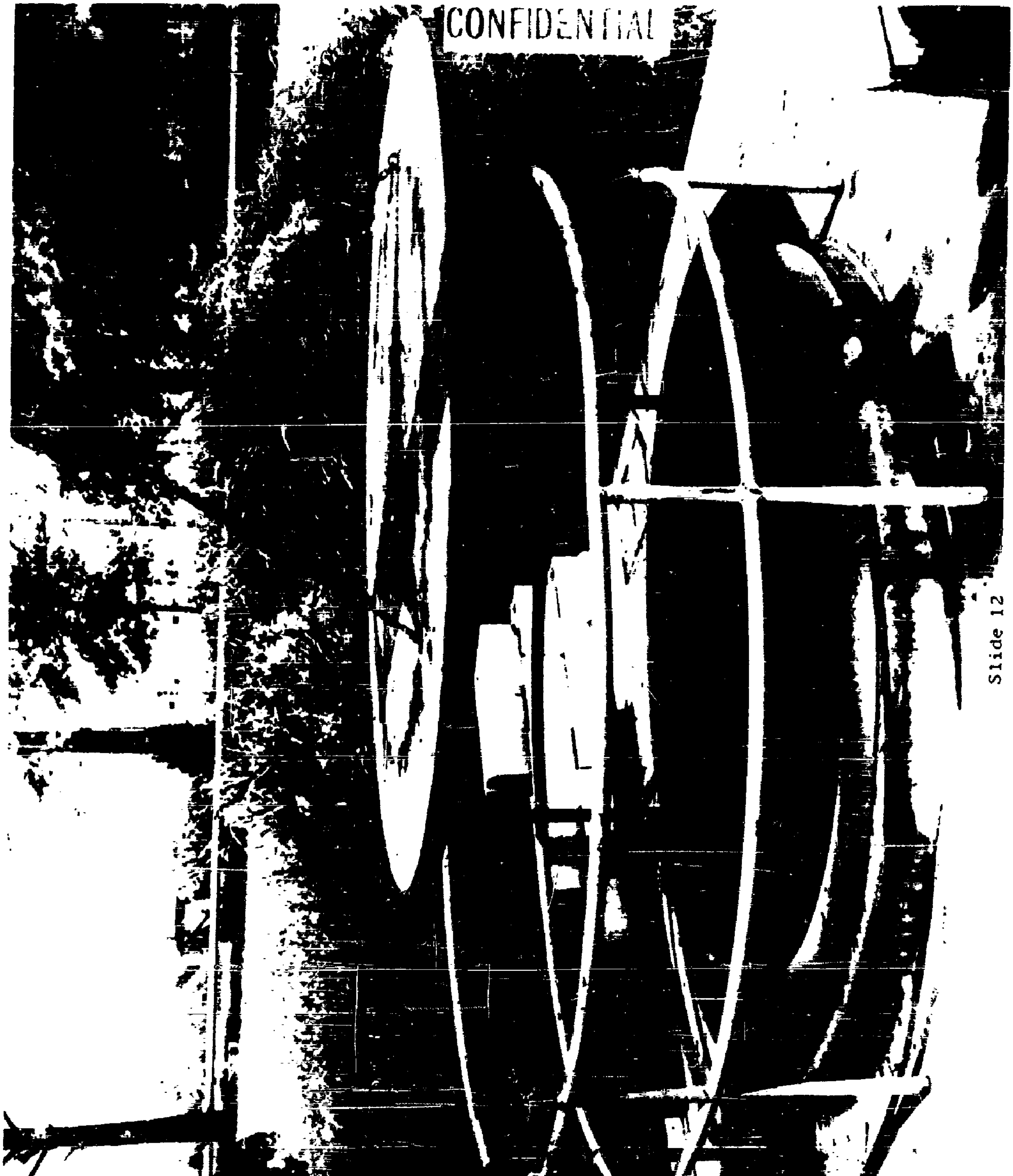

Slide 12

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Sympathetic detonation tests indicated that one pound of C-4 explosive would not initiate a pound of C-4 contained in a second pipe buried one foot away. High speed cinéma showed that both pipes remained in the ground, and that the fireball grew to a radius of only about five feet.

An all polyvinyl chloride pipe system is currently under consideration for fifty additional pipes now planned. The all plastic system would eliminate both the need for the polyethylene liner now used and the corrosion problems associated with steel.

Decontamination

Another common problem in explosive manufacturing is the decontamination of equipment which is to be modified, stored, or discarded. The oven shown in Slide 12 is used to decontaminate process equipment by heating to 500°F and holding for twelve hours. This temperature is considerably higher than that required to thermally decompose difluoramino compounds and derivatives of decaborane which are of current interest. Although plastic materials are not recoverable for reuse, metal components are effectively decontaminated with little degradation.

This paper has been an attempt to list the safety considerations in the small scale manufacturing of explosive chemicals. We have been averaging one explosion per month but nobody has been hurt from an explosive reaction in our Chemical Processing Group. On the surface this record is acceptable, but the few near misses which have occurred show that a safety program is never complete. We feel this so strongly that more than twenty five percent of the pilot plant engineers' time is devoted to searching out areas where we still depend upon good luck.

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THE SLURRY MIX PROCESS FOR NITROPLASTISOL PROPELLANT

by

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This paper reviews the turbine blade, plastic mix bowl method for making plastisol propellant, compares it with the method employing a standard vertical planetary mixer, and describes the benefits and operation of the planetary mixer ultimately selected, a modified Ross Company mixer. Ease of scale-up to production equipment and elimination of a practical ceiling to propellant viscosity for processing, not readily accomplished with the turbine system, are the principal benefits derived.

Throughout the history of solid propellants, the double base system in one form or another has been used more than any other propellant system. Initially, double base propellants were available only in extruded form, and usable grain configurations were limited in number. The development of the composite double base system provided the propulsion unit designer with a greater selection of grain configurations. An improved version of nitrasol propellant, the present Nitroplastisol propellant developed at Lockheed Propulsion Company (LPC), provides practically unlimited freedom to grain designers.

One of the principal benefits of Nitroplastisol propellant, is its processibility, which is due to its low viscosity as compared to rubber base composites having similar ballistic character. The fuel matrix of most rubber base propellants obtains all of the oxygen for combustion from an oxidizer which is normally in the form of crystalline ammonium perchlorate. To improve performance, other solid materials, such as aluminum powder, are utilized. Of necessity, high performance rubber base propellants are normally very viscous materials, and generally the flow characteristics are non-Newtonian. This high viscosity and non-Newtonian character requires heavy duty process equipment and, on occasion, pressurization of casting lines and vibration to permit casting of high quality grains.

On the other hand, Nitroplastisol propellant contains plasticizers which are nitrated esters which provide a source of oxygen to assist in conversion of fuel additives. The total solids content, including metallic additives and inorganic crystalline oxidizers, is normally in the range of 40 to 70 percent. At this solids loading, the specific impulse obtained from the propellant is higher than presently obtained in rubber base composite propellant. The low solids content results in low viscosity propellants which are nearly Newtonian in character and can be readily processed by the method designated the Slurry Mixing Process.

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Throughout the development of LPC's Nitroplastisol formulation, hazard tests have been performed on all ingredients and their combinations. In no instance did the propellants or the nitrated ester plasticizers exhibit a tendency to transit from deflagration to detonation. Tests of uncured propellant in quantity were normally performed with little or no confinement and the results were considered only partially applicable to processing in the planetary mixers.

Prior to adoption of a planetary mixer with a metal mixing bowl, it was deemed necessary to obtain additional assurance that a fire in the mixer would not transit to detonation. Two types of tests incorporating submerged ignition in a large propellant mass under confinement were performed. These are discussed below.

BURNING TEST NO. 1

Approximately 430 pounds of freshly mixed undeaerated Nitroplastisol propellant was poured into a partially buried heavy steel drum. Figure 1 depicts the test setup. Propellant depth was 20 inches with a depth-to-diameter ratio of 0.85. The drum lid, containing a small hole, was clamped in position, and the igniter (a modified Atlas Electric Match) was positioned 4 inches below the propellant surface. A 30-gallon steel drum containing sand was placed over the hole. The provided ballast imposed an approximately 4-psi restraint. Small samples of the propellant were placed around the drum to determine the flame pattern and area covered. Upon ignition, smoke and flame emerged around the edge of the ballast drum. At approximately 0.4 second, the ballast drum was pushed off and the propellant burned quietly until consumed. As shown in Figure 2, the drum did not clear the propellant container, indicating only a mild action. All propellant samples within a 15-foot radius burned.

BURNING TEST NO. 2

Approximately 200 pounds of freshly mixed undeaerated propellant was poured into a metal pressure vessel. The vessel was placed in the ground to a depth of 36 inches with the vessel's aft end protruding 6 inches above ground level. The depth of propellant was 27 inches at a diameter of 10 inches. Figure 3 shows the arrangement.

This test was meant to simulate the depth of propellant in the 85-gallon planetary mixer which at a maximum capacity has a propellant depth of 26 inches at a diameter of 30 inches. A modified Atlas Electric Match was inserted to a depth of $25\frac{1}{2}$ inches in the propellant. The aft opening was then covered with sand bags to provide a restraint of 35 psi internal pressure. Small containers of propellant were placed as in test 1.

Approximately one second after ignition, the sand bags were pushed to one side to vent about 10 percent of the possible venting area. The propellant burned quietly for about 7 minutes until it was consumed. Figure 4 shows the after-test condition. Again, shock pressurization did not appear to take place, and the small propellant samples were not consumed.

The results of these tests indicate that deflagration to detonation transition would not occur in the event of ignition of the propellant during mixing. These results and conclusions obviously apply only to the Nitroplastisol propellants developed at LPC and specifically tested for compatibility -- not to composite double base propellants in general.

For several years, LPC has mixed Nitroplastisol propellant by the slurry mix process in a turbine blade, plastic mix bowl system. Over three hundred 250-pound batches have been processed without incident. As utilized at LPC, the process comprises two steps. Figure 5 shows the mechanical arrangement. In the first step, the plasticizers, nitrocellulose (in the form of either Ball Powder or PGNC), aluminum, and stabilizer are blended together as indicated. Preconditioning of ingredients to a nominal 60°F temperature is sufficient to prevent the temperature rising to above 70°F due to normal mechanical heat of mixing. Because of the poor conductivity of the plastic bucket, this preconditioning is more practical than complicated cooling arrangements. In the second step, the inorganic oxidizer is added. A basic safety benefit, prevention of cross-contamination of the work area by organic materials and the oxidizer, is realized by the two-step mixing.

The simple turbine blade, plastic mix bowl process is one of the most practical and economical systems from the standpoint of cost of equipment. However, the turbine system is limited to use with propellant having an apparent viscosity of less than 200,000 cp; scale-up to large quantity production units is difficult. The demands for higher performance normally require an increase in solids content with a resultant increase in propellant viscosity that surpasses the process limits of the turbine system. Although the viscosity will be higher than is practical for the turbine system, it will still be one-third of the viscosity for comparable rubber base propellants.

To provide process capability for higher viscosity propellants and efficient scale-up to high rate production capacity, standard type vertical planetary change can mixers were deemed necessary. A survey of mixing equipment resulted in selection of a mixer made by Charles Ross & Son Company and modified to LPC specifications.

At the present time, LPC has in operation one 10-gallon Model No. Special 130 ELS mixer. An 85-gallon Model No. 130 CDM mixer is being installed. Figure 6 shows the 10-gallon mixer installed. The blades are raised to show design and position.

These two mixers are generally identical in design and function. The mixing can and all metal potentially exposed to the propellant is 304 stainless steel. The mixing cans have a total volume approximately 50 percent greater than the working capacity. The mixing cans and the inner and outer shells are fabricated to withstand internal pressure from 10 mm mercury absolute to 50 psi at temperatures between 180°F to 35°F. Two openings fitted with tri-clover clamps are provided in the bottom of the can for the purpose of providing bottom discharge and thermocouple well, as required.

The vacuum hood which connects the bowl to the mixer drive mechanism contains flange openings to permit addition of ingredients from a sealed system during the mix cycle. The main planetary gear housing is sealed with a liquid seal on the outside periphery to prevent contamination of the drive and gear mechanism. The seal between the vacuum hood and the mixing can is obtained with an O-ring.

Each mixer has two circular relief ports in the vacuum hood which rupture at 15±2 psig at ambient temperature. The diameters are 8 inches and 10 inches, respectively, for the 10-gallon and 85-gallon mixers.

The open square blade permits mixing full capacity batches without splashing and provides adequate shear to work the mass without excessive temperature rising due to mechanical heat input. The blades, mounted symmetrically off center, rotate about their individual axes at a 2 to 1 ratio and precess about the mixer with the planetary drive. The planetary and blade speeds are variable.

Two centering and holding fixtures are mounted at the rear of the mixing can to ensure definite pushing of the can. Explosion-proof micro-switches guarantee the positive engagement of the fixture and prevent mixer operation if not engaged.

Two important modifications, of the liquid seal between the planetary gear box and the housing and of the design of the packing gland and arrangement of the shaft seal, were made on the basic mixer. These modifications are shown in Figure 7.

The deep liquid seal prevents vapors and dry powder dusts from entering the planetary gear and drive mechanism. Routine sampling of the liquid provides a positive check of contamination. The sealant can be replaced readily. The shaft seal is essentially of two parts: (1) the upper section, which has three fitted Teflon packing rings of which the lower two are held in contact with the shaft by stainless steel garter springs, and (2) the lower section, which comprises a lantern ring and one fitted Teflon ring held with a garter spring. This arrangement is flushable through the flow channels shown.

The 10-gallon mixer was installed only recently. A complete mechanical checkout revealed some minor discrepancies that were easily remedied. Six full-scale test mixes have been made, and the results show excellent mixing action and temperature control. The temperature at all interfaces between moving parts was normal. Examination of the liquid seal on the planetary housing and shaft seals show no contamination by the propellant ingredients.

The jacketed mix bowl which incorporates circulation of controlled temperature water has eliminated the requirement for conditioned storage of raw materials and will effect reduction of over-all facilities and total mix cycle, as anticipated.

The favorable results obtained in these initial mixes has demonstrated that LPC's decision to utilize the more universal vertical change can mixer is a real advance in Nitroplastisol propellant processing.

Because of basic differences between compositions of LPC Nitroplastisol and composite double base propellants manufactured elsewhere in the industry, a recommendation for industry-wide use cannot be made.

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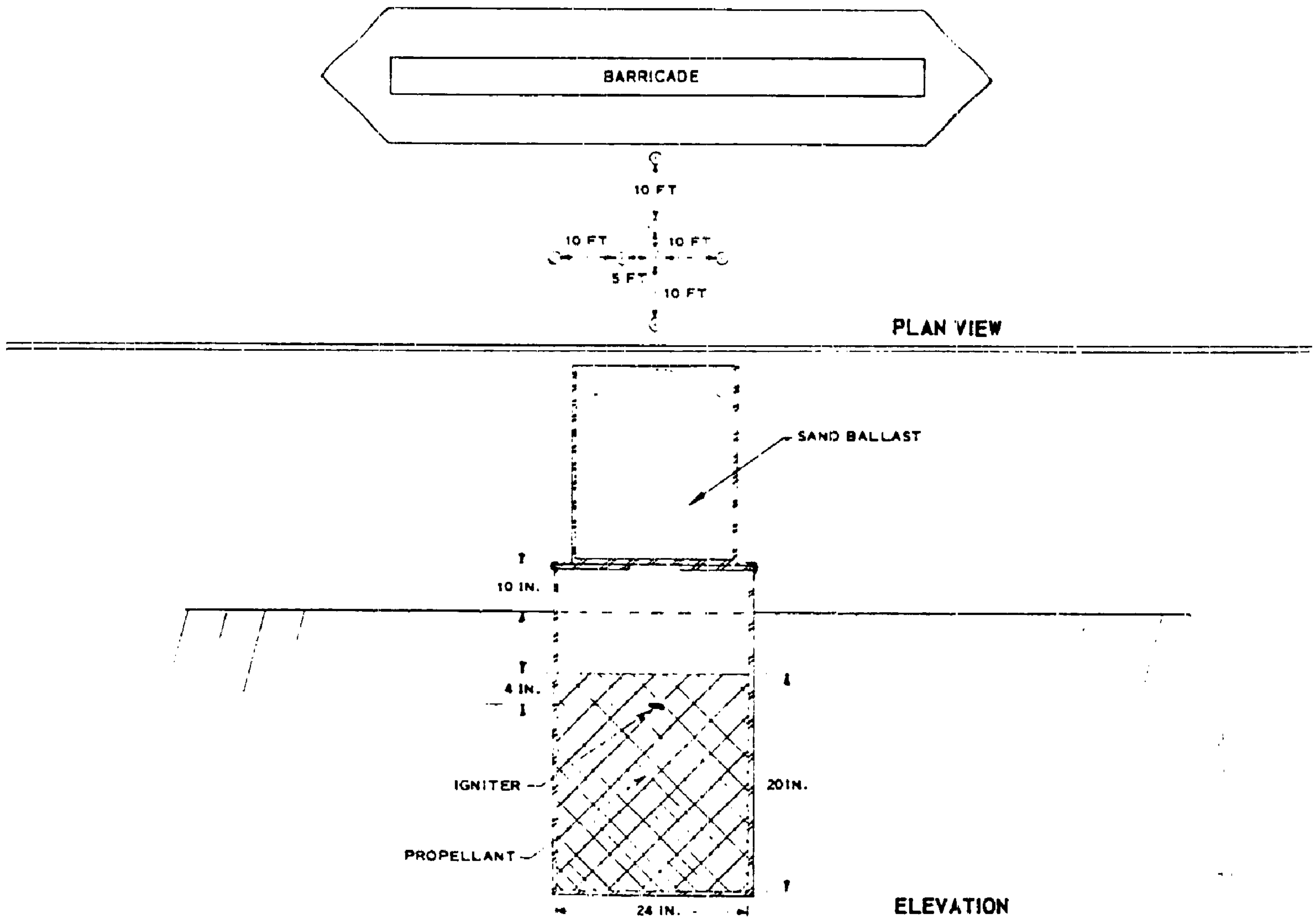

Figure 1 Test Setup, Nitroplastisol Propellant Burning Test No. 1

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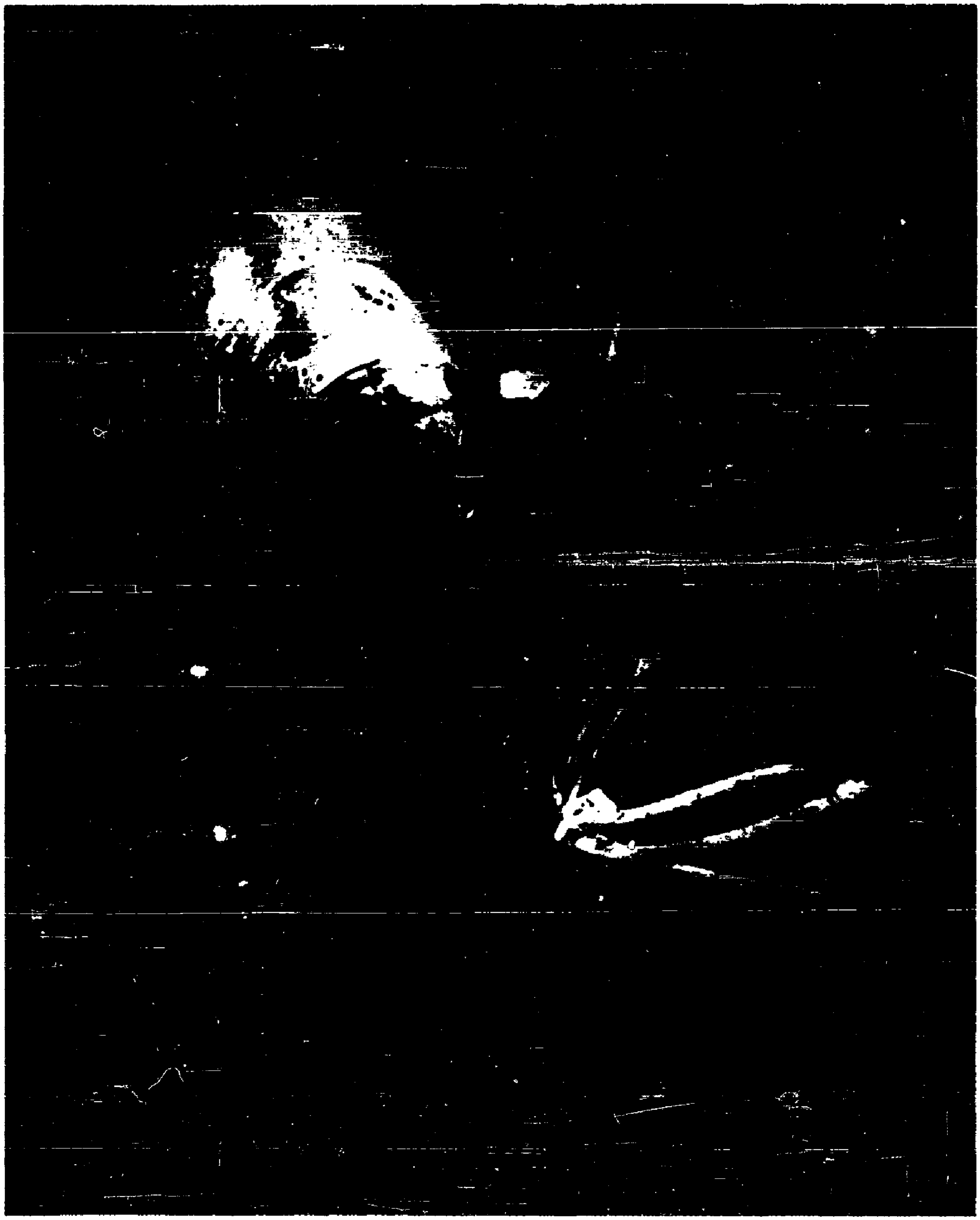

Figure 2 Post-Fire, Nitroplastisol Propellant Burning Test No. 1

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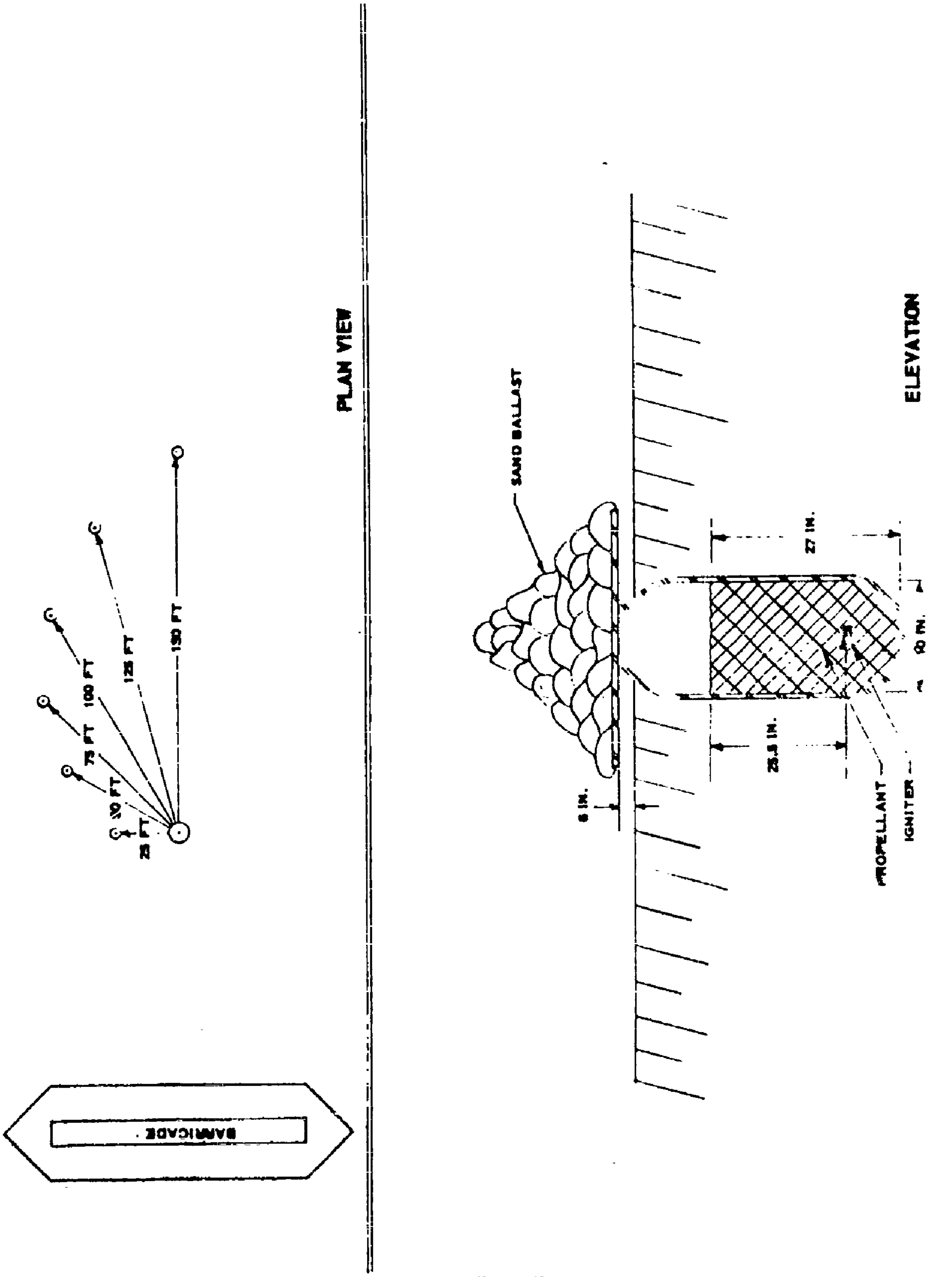

Figure 3 Test Setup, Nitroplastisol Propellant Burning Test No. 2

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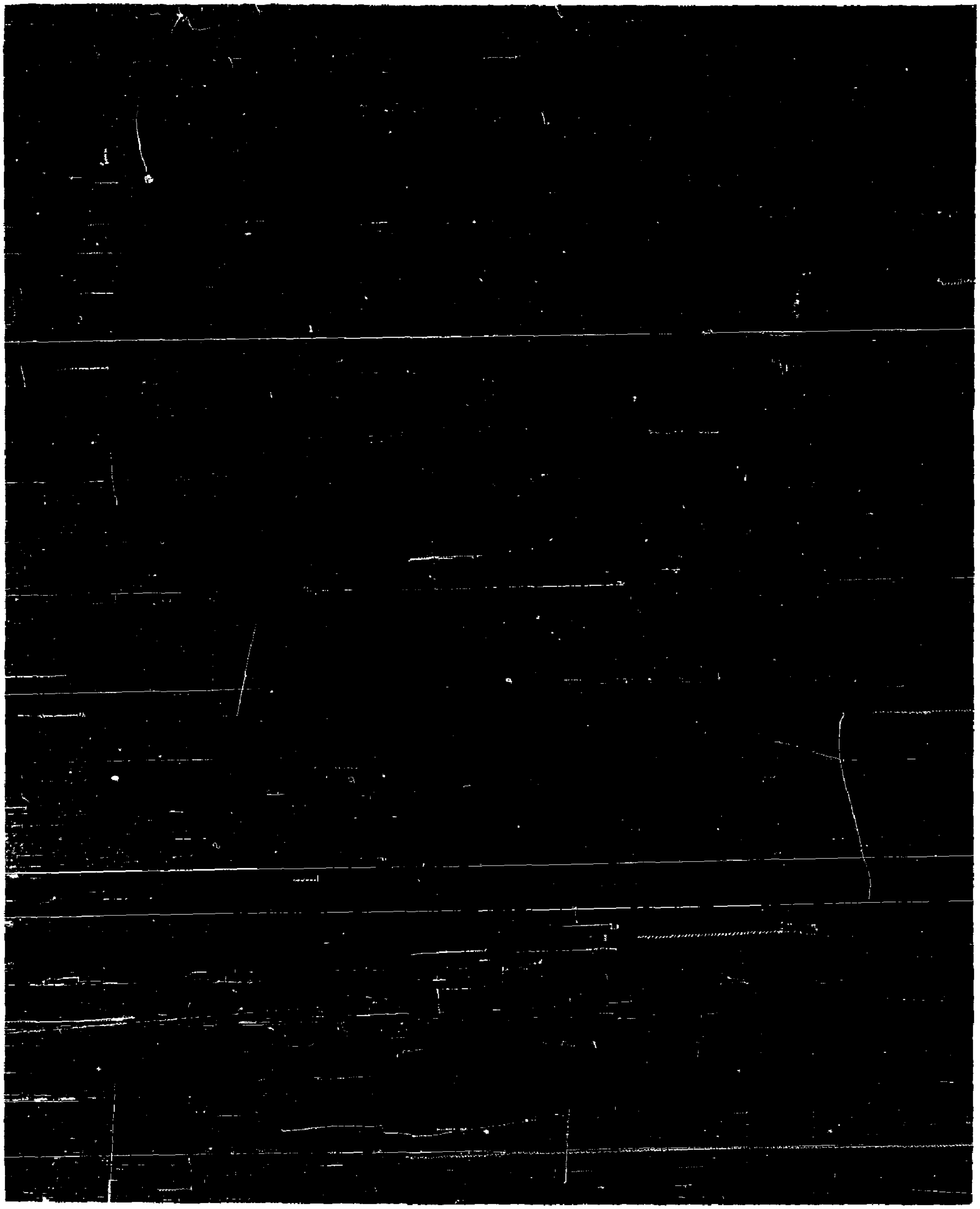

Figure 4 Post-Fire, Nitroplastisol Propellant Burning Test No. 2

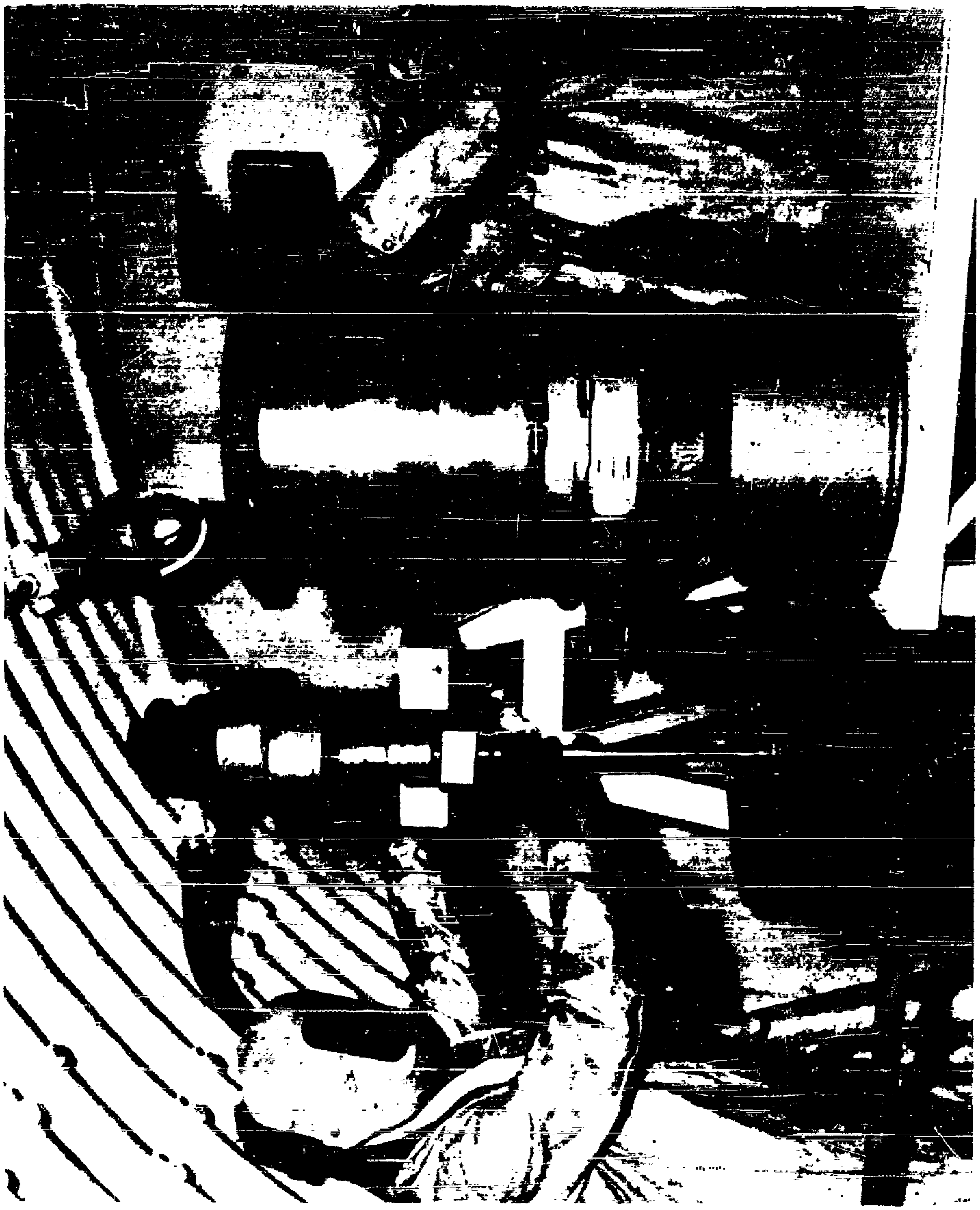

Figure 5 Turbine Blade, Plastic Bowl Mixing Equipment

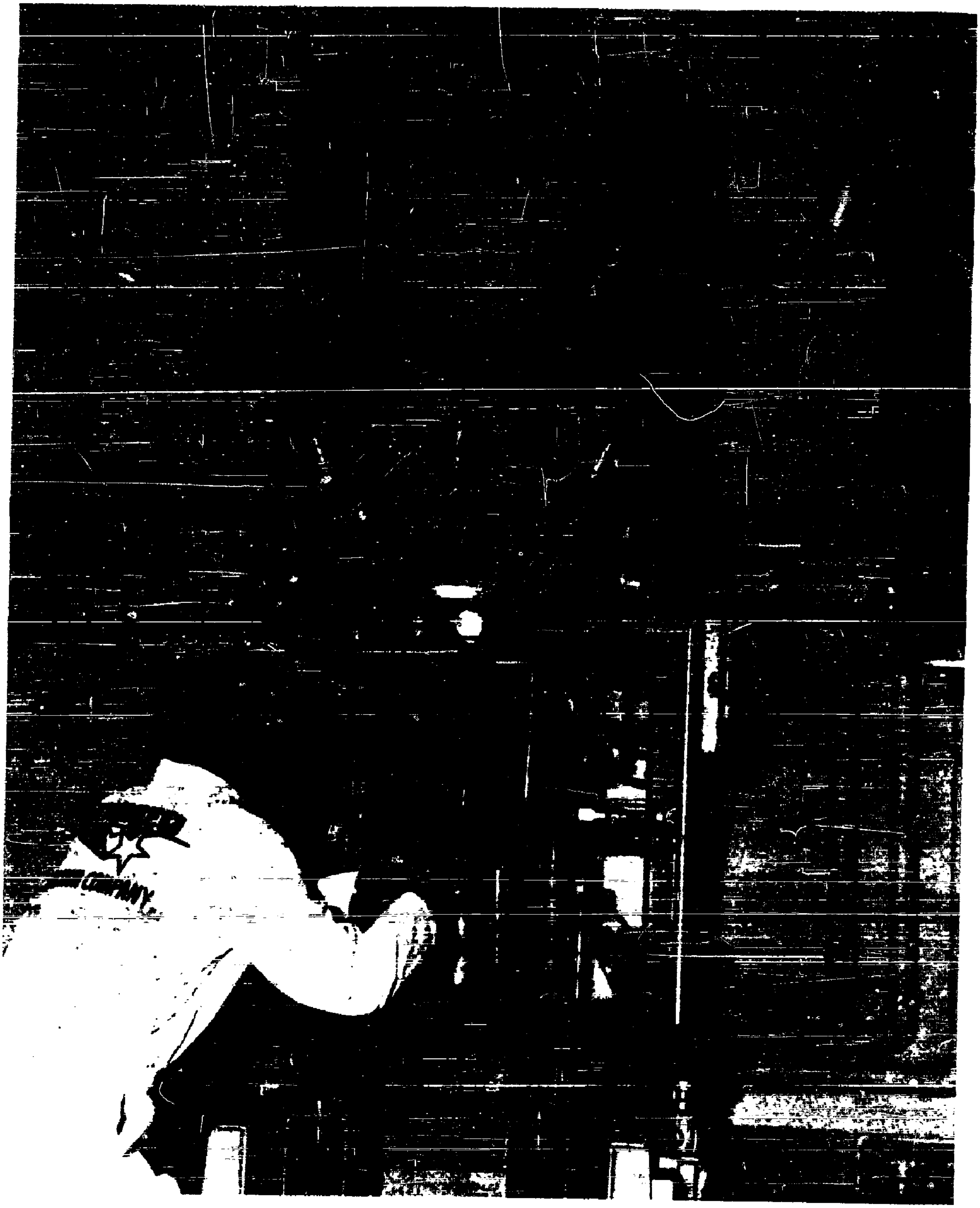

Figure 6 Ten-Gallon Planetary Mixer

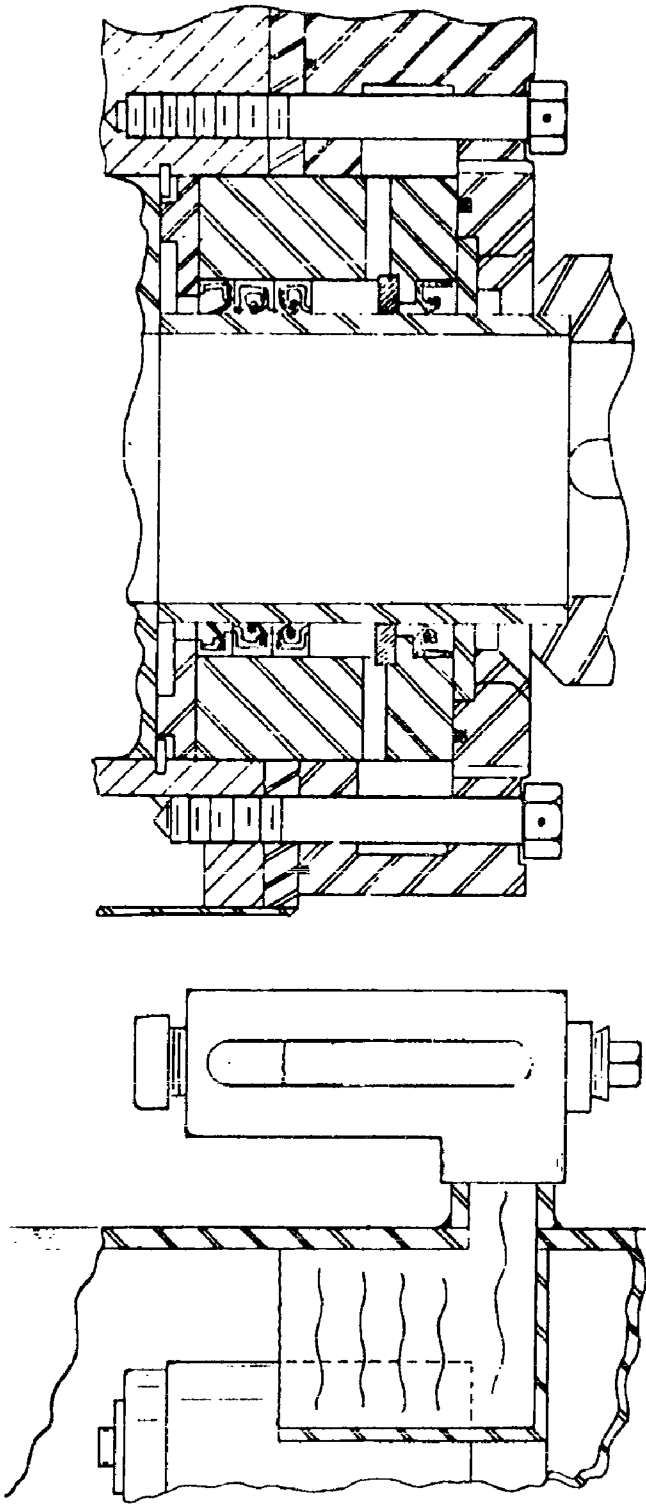

Figure 7 Ross Mixer Seal Details

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DEMONSTRATION

on

FLAME PROPAGATION & EXPLOSION-PROOF ELECTRICAL EQUIPMENT

by

H. E. Poland
Bureau of Mines
Department of the Interior
Oakland, California

UNCLASSIFIED

SAFETY SAMPLING PROGRAM

by
C. D. Attaway
Thiokol Chemical Corp., Longhorn Div.

Great strides and vast improvement have been made in accident prevention in solid rocket motor manufacture, but as production processes become more complicated and more and more products, methods, materials, machines and equipment become a part of the industry, new safety problems are constantly arising. Accidents continue to plague every plant and the cost of Workman's Compensation, medical treatment, insurance, and wages continues to mount.

We recruit employees, test them, examine them, hire them, indoctrinate and orient them, assign them, and counsel them. In attempts to protect them we train them, school them, warn them with signs, posters, and billboards, guide them with SOP's, procedures and methods, and instruct them with safety meetings and safety films. Then we inspect and check on their working area and equipment, correct dangerous situations, provide personal protective equipment, and give them guarding devices and safety tools.

Yet employees continue to injure themselves and damage property through accidents.

We do a thorough job of investigating, analyzing, reporting, recording and taking corrective actions after an accident. Important as this is to a safety program, it is "after the fact" - too late to provide effective control and prevent the accident. It is apparent that we need the facts on our safety situation as of the moment - not those compiled in reports that are a week, month, or year old.

We need a method to pinpoint the accident-producing unsafe acts before the accident happens, rather than compile histories and statistical reports on accidents that have already occurred.

This program is believed to be an answer to that need. It has been specifically designed to attack the "unsafe act" and by a slight variation of the method can be used equally well for the "unsafe physical or mechanical condition" or to maintain "good housekeeping".

While this technique has been successfully applied in other manufacturing industries, to our knowledge this is the first time that it has been used in the solid propellant industry.

Safety Sampling Program

DEFINITION

The basic concept of work sampling is patterned after the quality control principles employed throughout industry. Industry for many years has employed the receiving inspection technique whereby a random selection of a number of objects is carefully inspected in order to determine the probable quality of the entire shipment. The degree of accuracy desired dictates the number of random selection items which must be carefully inspected. The greater the number inspected the greater the accuracy.

The same principle can be applied to determine the percentage of safe work activity. We will concern ourselves with work sampling only as it applies in determining the percentage of safe or unsafe work practices of our employees. This technique will be defined as "safety sampling". It is a method of measuring safety performance by use of instantaneous observations in order to produce a safety performance analysis. It is accomplished by employing the principles and techniques of random sampling, using the observation procedure set forth in this program.

SCOPE

Each Safety Engineer and/or Safety Inspector will conduct a series of random inspections of all solid rocket manufacturing facilities of the plant. Such inspections are to be made at least once each day over the period of time required, in order to determine the percentage of safe or unsafe employee activity

PURPOSE OR OBJECTIVES

A. To establish a method of determining the safety performance of work force in the plant.

B. To pinpoint the unsafe practices which occur or exist in our operations by type, area, and supervisory responsibility.

C. To present formal safety activity reports to management which indicate the areas where greater efforts in education, instruction, and enforcement of safe practices must be directed so as to prevent the occurrence of accidents.

D. To obtain data which will indicate the progress or lack of progress in our accident prevention program as related to instilling safety in the minds of our employees.

I. PREPARATORY STEPS

The preparatory steps taken in effecting this type of study are as follows:

A. The Safety Department should contact qualified personnel in the plant skilled in work sampling techniques, such as industrial engineers, and secure their assistance and cooperation in setting up the program and training Safety personnel.

B. The Safety Director or Chief Safety Engineer will then select an area of the plant to be studied based on an analysis of previous years accident experience.

C. Using an element code list of unsafe acts or practices such as ASA Code Z16.2 (Exhibit 1 & 2) and the Safety Sampling Data Sheet (Exhibit 3), the Safety representatives will make a preliminary or trial trip, through the selected area to establish a route, determine the number of observations required and the time required for each trip.

D. Based on the time required per trip and amount of other work, a good estimate can be made of the number of inspection trips each Safety representative can make during the day.

E. Random starting times will be selected for each trip each day. Consideration will be given to idle periods and lunch periods. However, care must be exercised to eliminate any set pattern of starting times.

II. CALCULATIONS

The number of observations required is based on the preliminary survey and the degree of accuracy desired. The following data will be recorded on the preliminary survey:

a) Total observations

b) Unsafe observations

The percentage of unsafe observations is then calculated. Using this percentage (P) and the desired accuracy which we will determine as plus or minus 10%, we can calculate the total number of observations required (N) by using the following formula.

$$N = \frac{4 \quad (1-P)}{Y^2 \quad (P)} \qquad \text{(Exhibit 3A)}$$

Where: N = Total number of observations required

P = Percentage of unsafe observations

Y = Desired accuracy (Percentage)

Example:

If the preliminary survey produced the following results:

(a) Total observations - 126

(b) Unsafe observations - 32

The percent of unsafe to total observations would be 32 divided by 126 which equals .254 or 25%.

A $\pm$ 10% desired accuracy would mean that 95% of the time the correct answer falls between 22.5% and 27.5% of the total.

$$N = \frac{4 \quad (1-P)}{Y^2 \quad (p)} = \frac{4 \quad (1-.25)}{(.10)^2 \quad (.25)} = \frac{3}{.0025} = 1200$$

Observations required.

This study then must have a minimum of 1200 observations to give effective results. The above method of calculating the required number of observations is given for information only. However, once the percent of unsafe activity is determined from the initial or trial survey, the program of random times and number of observation trips daily should be established.

III. <u>OBSERVATION PROCEDURE</u>

When the random starting times and number of trips required have been determined, the Safety representative is prepared to make his first tour of the selected area. Equipped with a clipboard, pencil, Safety Sampling Data Sheet (Exhibit 3), and unsafe act code, he goes to the area, according to his random time schedule.

He identifies the area or building, the supervisor responsible, and the tour time on the Safety Sampling Data Sheet. He then proceeds through the area or building observing <u>every employee who is engaged in some form of activity</u> and instantaneously records a safe or unsafe observation of the employee. If no activity or work is going on at the time that involves the operations under study, the tour is cancelled. Each employee is observed only long enough to make a determination and once the observation is recorded it should not be changed. If the observation of the employee indicates that he is performing his job safely, a small check is entered in the safe observation column. If the employee is observed performing an unsafe practice, a check is made in the column which indicates the type of unsafe practice by the code number on the Safety Sampling Data Sheet. He does not stop to investigate or quiz the employee.

IV. <u>TABULATING THE RESULTS OF THE STUDY</u>

When the required number of observations have been accomplished, the results can be compiled in many different forms. However, the final report should include the following as a minimum

a) Safety Sampling Data Sheet Recap - General Codes Unsafe Acts.

b) Types of Unsafe Acts Observed Recap - Detailed Classifications.

c) Supervision Breakdown by Buildings - Unsafe Acts %.

d) Supervision Breakdown by Operations - Unsafe Acts %.

V. ANALYSIS OF RESULTS

The Safety Sampling Program at Thiokol-Longhorn began with a preliminary survey of our propellant production facilities during February, 1963. This preliminary survey indicated that approximately 5,000 sampling observations would have to be made to produce an accuracy of ± 10%.

For the next three months, safety representatives made random samplings on all shifts of operations and by June, 1963 a total of 4,952 observations in the form of Safety Sampling Data Sheet reports were accumulated.

These were analyzed and compiled into the final reports resulting in the following conclusions:

1) Safety Sampling Data Sheet Recap (Exhibit 4)

This reveals that out of 4,952 observations, there were 217 which are defined and coded by ASA Code Z16.2 as unsafe. This represents 4.38% unsafe acts. The accuracy of this result is 95% which means that the percentage of unsafe acts at all times will fall between 3.79% and 4.97%. For comparison's sake, the expected rate of unsafe acts in Industrial Operations is 9.1% based on the Heinrich formula that out of 330 specific operations there will be 30 unsafe acts, one of which will result in a disabling injury.

This recap shows that the predominant general classification unsafe act is "non-use of safe attire and personal protective equipment", confirmed by 125 unsafe act observations. This represents 57.5% of all the unsafe acts. In second place with 24 unsafe act observations is "taking unsafe position or posture" and in third place with 21 unsafe acts is "using unsafe equipment", while in fourth place, but most important, are 19 unsafe acts of "unsafe loading". These four general classifications account for 189 unsafe acts or

89% of all unsafe act observations. The other 28 unsafe acts are scattered over five other classifications.

This recap indicates the areas where corrective action must be applied. To pinpoint the specific unsafe acts, a breakdown to detailed classification is needed.

2) Types of Unsafe Acts Observed (Exhibit 5)

Out of the 125 unsafe acts concerning attire and personal protective equipment, we have 50% of 62 "failurs to wear gloves, goggles, masks, etc." Also revealed are 49 instances of "ragged clothing, loose shoe strings, etc." and 9 cases of "wearing ties, rings, watches, etc. in hazardous areas". Next highest are 16 reports of "unsafe arranging, placing and parking".

With these unsafe acts listed in detail, the safety man can quickly see the human errors in need of correction. However, he needs to know the location producing these unsafe acts.

3) Supervision Break-down by Buildings (Exhibit 6)

This recap shows Building 32-H, Fixture Preparation, with the highest percentage or 9.6% unsafe acts, followed by Building 50-G, Parts CLeaning, with 9.1% and Building 25-C, Oxidizer Grinding, with 8.7%. Building 68-C, Finish and Packout, has the lowest percentage with only one unsafe act out of 118 observations. From this information, the safety man can determine the exact supervisor having the most unsafe acts in his operations.

4) Supervisor Break-down by Operations (Exhibit 6)

This analysis reveals that oxidizer grinding and blending has a 7.2% of unsafe acts and identifies the supervisor responsible. Other operations range from 6.4% to 3% and identify the individual supervisors. It is pleasing to note that in mixing, a most hazardous operation, there were only 16 unsafe acts out of 535 observations. Only two of our supervisors out of 10 had an unsafe act record above the 4.38% revealed by the survey.

CONCLUSION

With this collection of information, the alert safety man will have answers to where unsafe acts are taking place, what the unsafe acts are, when they are being committed, and who is responsible for their existence or elimination.

At Thiokol-Longhorn we are putting this information to corrective use in finding out WHY the unsafe acts are happening and HOW to prevent them and we are doing it NOW.

SAFETY SAMPLING CODE

THE UNSAFE ACT

(Common Infractions of Safe Working Practices)
ASA Code Z16.2

Code	GENERAL CLASSIFICATIONS
0	Operating without orders or authority
1	Operating or working at unsafe speed
2	Making safe device inoperative
3	Using unsafe equipment, hands instead of tool, etc.
4	Unsafe loading, placing, stacking, etc.
5	Taking unsafe position or posture
6	Working on moving, dangerous, or exposed equipment
7	Distracting, teasing, startling, horse-play, etc.
8	Failure to use safe attire or personal protective equipment
9	Unsafe acts, miscellaneous

Exhibit No. 1

SAFETY SAMPLING CODE

Code	DETAILED CLASSIFICATIONS - (For Use on Data Sheet)
0	Operating without orders or authority
00	Starting, stopping, using, moving, etc., without authority
01	Starting, stopping, using, moving, etc., without giving proper signal
02	Failure to secure or warn, block, lock, or fasten chain, valve, switch, etc.
03	Failure to shut off equipment not in use
04	Lifting or releasing loads, etc., without giving warning
05	Failure to display SOP, warning signals, lights, signs, etc.
06	
07	
08	
09	Miscellaneous, not elsewhere classified

Exhibit No. 2

UNCLASSIFIED

SAFETY SAMPLING DATA SHEET SUPERVISOR:	Observer								Date Time		
	Area/Bldg.										
General Codes - Unsafe Acts	Sub-Codes -- Unsafe Acts										Tot. Uns
	00	01	02	03	04	05	06	07	08	09	Acts
00 Operating w/o orders or Authority											
10 Operating or Working at Unsafe Speed											
20 Making safe device inoperative											
20 Using unsafe equipment											
40 Unsafe loading											
50 Taking unsafe position or Posture											
60 Working on moving, dangerous, or Exposed equipment											
70 Distracting, teasing, horseplay											
80 Non-use of safe attire, Personal protective equipment											
90 Unsafe acts, miscellaneous											
Safety Activity Observations											

Exhibit No. 3

UNCLASSIFIED

FORMULA

SAFETY SAMPLING

$$N = \frac{4\,(1-P)}{Y^2\,(P)}$$

Where
N = No. of observations required
P = % of unsafe observations
Y = Desired accuracy (%)

EXAMPLE:

If the preliminary survey produced the following results:

Total observations - 126

Unsafe observations - 32

THEN $P = \frac{32}{126} = .254$ or 25%

$Y = \pm 10\%$ the desired accuracy.

SUBSTITUTING:

$$N = \frac{4(1-P)}{Y^2\,(P)} = \frac{4(1-.25)}{(.10)^2\,(.25)} = \frac{3}{.0025} = 1200 \text{ observations required.}$$

Exhibit No. 3A

UNCLASSIFIED

COMPOSITE

SAFETY SAMPLING DATA SHEET		Observer: Safety Personnel						Period Mar. - June 1963			
		Area/Bldg. Plant 3						Time Various			
		Sub-Codes - Unsafe Acts									Tot. Uns.
General Codes - Unsafe Acts		00	01	02	03	04	05	06	07	08	09	Acts
00	Operating w/o orders or Authority		1									1
10	Operating or Working at Unsafe Speed				1	1						2
20	Making safe device inoperative	1	1		3						3	8
30	Using unsafe equipment	5	7			6					3	21
40	Unsafe loading	2		1	16							19
50	Taking unsafe position or Posture	2				2	1	4	6	2	7	24
60	Working on moving, dangerous, or Exposed equipment	1				8						9
70	Distracting, teasing, horseplay		3	2	2	1						8
80	Non-use of safe attire, Personal protective equipment	62	49	9	3	2						125
90	Unsafe acts, miscellaneous											0
Safe activity Observations - 4735											Total 217

Exhibit No. 4

UNCLASSIFIED

UNCLASSIFIED

SAFETY SAMPLING ANALYSIS

TYPES OF UNSAFE ACTS OBSERVED

Bldg./Area Plant 3 Period Mar. - June 1963

UNSAFE ACT	CODE NO.	NO. OF OBSERVATIONS
Starting, stopping, using, etc., without authority	01	1
Jerking, yanking, swinging, moving, throwing	13	2
Removing safety devices, blocking, plugging, tying, etc.	20	2
Improper adjusting, changing, setting safety devices	23	3
Miscellaneous - unsafe safety device acts	29	3
Using defective, bent, cracked tools or equipment	30	5
Unsafe use or method with tools or equipment	31	13
Miscellaneous - unsafe use of equipment, tools, machines	39	3
Overloading - hoist, cable, sling, vehicle, cart, etc.	40	2
Carrying or lifting too heavy load by hand	42	1
Unsafe placing, arranging, parking	43	16
Under suspended load	50	2
Improper lifting	54	2
Standing on pipes, cables, beams, machine, etc.	56	10
Exposure to sliding, falling, slipping loads	58	3
Miscellaneous - Unsafe position or posture	59	7
Getting on and off moving machines, vehicles, etc.	60	1
Welding, repairing in dangerous gases, materials	64	8
Throwing, pitching, playing, joking	71	5
Pushing, quarreling, tickling, goosing	73	3
Failure to wear masks, gloves, goggles, etc.	80	62
Wearing ragged clothes, sleeves, shoe strings	81	49
Wearing ties, rings, watches in danger areas	82	9
Failure to wear head covering, hard hats, boots, etc.	83	5
	TOTAL	217

Exhibit No. 5

UNCLASSIFIED

SAFETY SAMPLING ANALYSIS

SUPERVISION BREAKDOWN

BY BUILDINGS

PERIOD March - June 1963

Plant 3 - Production

BUILDING/AREA	IMMEDIATE SUPERVISOR	SECONDARY SUPERVISOR	SECTION OR DEPARTMENT HEAD	TOTAL OBSERVATIONS	UNSAFE OBSERVATIONS	PERCENT UNSAFE ACTS
Metal Parts Prep. 28-G	K. Duncan	B. Clark	J. T. Kerr	717	29	4.0%
Fixture Prep. 32-H	J. Scrivener	B. Clark	J. T. Kerr	135	13	9.6%
Fuel Mix/Blend 31-G/33-G	J. Scrivener	B. Clark	J. T. Kerr	286	5	1.7%
AP Grind 25-C	B. Doss	B. Clark	J. T. Kerr	46	4	8.7%
AP Blend 25-D/29-D	B. Doss	B. Clark	J. T. Kerr	245	17	6.9%
Mixing 41-E	J. Duck	B. Clark	J. T. Kerr	250	9	3.6%
Mixing 42-E	J. Duck	B. Clark	J. T. Kerr	285	7	2.5%
Cast/Core/ Cut-back/45-E	L. Morgan J. Denny	T. Taylor	J. T. Kerr	1522	64	4.2%
Cast/Core/ Cut-back/54-H	V. Grubbs	T. Taylor	J. T. Kerr	107	8	7.5%
Cast/Pack-Out 54-G	V. Grubbs	T. Taylor	J. T. Kerr	250	7	2.8%
Cast/Cure Cut-back/54-F	G. Slaughter	T. Taylor	J. T. Kerr	269	12	4.5%
Parts Cleaning 50-G	G. Slaughter	T. Taylor	J. T. Kerr	197	18	9.1%
Pack-Out 62-D	R. Lundy	T. Taylor	J. T. Kerr	191	8	4.2%
Pack-Out 68-C	R. Lundy	T. Taylor	J. T. Kerr	199	4	2.0%
Finish/Pack-Out 68-F	R. Wallace	T. Taylor	J. R. Kerr	118	1	0.8%
Finish/Pack-Out 75-I	R. Wallace	T. Taylor	J. T. Kerr	135	11	8.1%

Exhibit No. 6

UNCLASSIFIED

SAFETY SAMPLING ANALYSIS

SUPERVISOR BREAKDOWN BY OPERATIONS

Bldg./Area Plant 3 - Production   Period Mar.-June 1963

SUPERVISOR & OPERATIONS		TOTAL OBSERVATIONS	UNSAFE ACTS	PERCENTAGE
B. Doss	Oxidizer grinding and blending	291	21	7.2%
G. Slaughter	Casting, curing, cutback, cleaning	466	30	6.4%
R. Wallace	Finish, pack-out	253	12	4.8%
J. Scrivener	Fixture preparation, fuel mixing, blending	421	18	4.3%
L. Morgan J. Denny	Casting, cure, cut-back	1522	64	4.2%
V. Grubbs	Casting, cure, cut-back, pack-out	357	15	4.2%
K. Duncan	Metal parts preparation	717	29	4.0%
J. Duck	Mixing	535	16	3.0%
R. Lundy	Final assembly, pack-out	390	12	3.0%

Exhibit No. 7

UNCLASSIFIED

HAZARD CLASSIFICATION OF LARGE SOLID PROPELLANT ROCKET MOTORS

by

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ABSTRACT

The need for new transportation and deployment safety approaches has become apparent with the advent of large solid propellant motor systems. An extensive research program was conducted to develop some new approaches for the Air Force MINUTEMAN ICBM. This wealth of information was used as a basis for determining hazard classification and operational siting for the MINUTEMAN system.

This paper presents a review of the MINUTEMAN hazard classification study and resulting safety criteria. The information obtained through the MINUTEMAN program will then be applied to two new and larger solid propulsion systems being considered for ICBM applications - the Large Payload MINUTEMAN and the 156 Inch ICBM's.

Future Large Payload MINUTEMAN and 156 Inch ICBM systems are defined in detail with respect to size, weight, and predicted hazard classification for the propellants to be used.

[1] Manager, Advanced ICBM and Space Systems
[2] Manager, Safety and Security

Potential problems associated with the transport and the deployment of these ICBM's, which possess gross propellant weights from one-quarter to one and one-half million pounds, are analyzed. Required confirmation testing is discussed in detail.

INTRODUCTION

Thiokol Chemical Corporation was assigned as development contractor for the Stage I Motor of the MINUTEMAN ICBM. MINUTEMAN development began in early 1958 with a feasibility demonstration and the motor became operational early in 1962. Stage I Motor development tasks included subscale testing involving Stage II MINUTEMAN Motors and a complete propellant hazard classification program. The tasks also included laboratory tests, field tests, subscale tests, and full-scale motor hazard classification testing. Test results indicated that both the Thiokol Stage I and Stage II Motors were properly categorized as Class 2.

Based upon the MINUTEMAN hazard classification testing, a combined TNT equivalent value of approximately five percent of the total propellant for the Stage I Motor, 20 percent for the Stage II Motor, and 100 percent for the Stage III Motor, were assigned. The total combined TNT equivalent force was determined to be approximately 7,500 pounds of TNT.

In March of 1963, the Air Force assigned a study program to Thiokol requiring a study of Large Payload MINUTEMAN Propulsion Systems. In May of the same year, the 156 Inch Motor Feasibility Demonstration Program was similarly assigned. In support of these programs and requests from industry for data, Thiokol conducted extensive studies resulting in design definitions of 120 and 156 Inch Propulsion Systems. Since these are strategic systems, and contain total propellant weights

greater than the MINUTEMAN System by a factor of five to 25 times, Thiokol included hazard classification and siting considerations in their Large Payload ICBM Studies.

The Large Payload ICBM Studies for both the 156 Inch and Large Payload MINUTEMAN Systems have considered both Class 2 and Advanced Technology Class 9 Propellant Systems. In the case of the Large Payload MINUTEMAN Program, the deployment mode plan is designed to use current MINUTEMAN silos with their associated siting. The 156 Inch ICBM Program, being five times the over-all gross weight of the Large Payload MINUTEMAN System, is being considered for deployment in the ATLAS and TITAN-type silos.

Since the Large Payload MINUTEMAN and 156 Inch ICBM Systems are greater in diameter than the MINUTEMAN System (120 and 156 inches compared to 66 inches), the question arises as to the effect of the diameter increase on the TNT equivalent of the propellant. MINUTEMAN test results clearly established the Class 2 hazard classification up to the MINUTEMAN 66 inch diameter. Reaction wave velocities in the 66 inch diameter propellant samples predict that no appreciable increase in TNT equivalent or detonability will arise in either the 120 or 156 inch propellant diameters.

To confirm this prediction, Thiokol has studied the possibility of limited confirmation testing to the requirements of TO-11A-1-47. These tests along with the test schedules are presented in this paper.

MINUTEMAN MISSILE SYSTEM

The MINUTEMAN Missile System is comprised of three stages which have been developed by Thiokol Chemical Corporation, Aerojet General Corporation, and Hercules Powder Company. Design characteristics of the missile system are shown

in Figure 1. It will be noted that the three stages are joined together with interstage structure providing a free volume between stages. The warhead is mounted on top of the Stage III Motor and contains a high explosive charge which triggers the warhead. This small charge is capable of being detonated and inducing a detonation wave into the Stage III Motor.

The Stage I Motor, developed by Thiokol is shown in Figure 2. The Stage I Motor is 65.5 inches in diameter and 294.5 inches long. It is contained by a high strength steel pressure vessel capable of withstanding pressures to approximately 900 psia. The propellant in the Stage I Motor is a PBAA/Al/AP formulation and approximately 45,500 pounds of this propellant are contained in the motor. Due to the large size of this motor, Thiokol has placed considerable emphasis on subscale and full-scale hazard classification testing to isolate possible hazards associated with transportation, handling, storage, and use of the Stage I rocket motor.

The Stage II and III rocket motors contain approximately 12,500 and 3,500 pounds of propellant, respectively, resulting in a MINUTEMAN System weight of approximately 60,000 pounds Hazards associated with the missile system must be considered for the individual stages and the completely assembled missile containing 60,000 pounds of high energy propellant.

Modes of transportation used in the MINUTEMAN System include the primary modes of highway and air transportation. The motors are shipped from the manufacturing plant over public highways in a transporter such as the one shown in Figure 3. After the individual motors are assembled into a complete missile system at the Hill Air Force Base Assembly Plant, Ogden, Utah, the completed

missile is delivered to the operational site by air transportation (Figure 4). At the operational site the missile is removed from the aircraft and placed in a transporter erector which is used to transfer the missile from the aircraft to the launch facility (Figure 5).

The MINUTEMAN missile is emplaced from the transporter erector into the MINUTEMAN launch facility as shown in Figure 6.

The MINUTEMAN System has been briefly reviewed to establish a base for discussing future larger payload missile systems. MINUTEMAN hazard classification results will be briefly reviewed in order to establish a basis for comparison of the larger proposed systems.

MINUTEMAN HAZARD CLASSIFICATION TESTING

Thiokol was responsible for conducting hazard classification tests on the Stage I Motor of the MINUTEMAN Missile System. In addition, classification tests were conducted on the Thiokol-developed Stage II MINUTEMAN Motor.

Hazard classification requirements for the testing are summarized in Table I.

TABLE I

IMPOSED REQUIREMENTS FOR
EXPLOSIVE CLASSIFICATION TESTS OF THE
PROPULSION SYSTEM FOR WEAPON SYSTEM 133AA(MINUTEMAN).

REF: GM 59.7650.3-36

A. LABORATORY TESTING

a. IMPACT SENSITIVITY TESTS

(1) 50 explosions at one height condition

TABLE I (Cont)

b. AUTO-IGNITION

(1) 1 hour test

(2) 8 hour test

B. <u>FIELD TEST</u>

a. SUSCEPTIBILITY TO DETONATION

(1) 30 tests unconfined, 10 ea-(60, 80 and 100°F)

(2) 30 tests confined, 10 ea-(60, 80 and 100°F)

C. <u>FULL-SCALE OF PROTOTYPE SUBSCALE MOTOR TESTS</u>

a. SUSCEPTIBILITY TO DETONATION (100 lb max RDX Booster)

<u>Each Stage</u>

(1) 4 Subscale Prototype Test

(2) 2 Full-Scale Tests (minimum)

b. HIGH VELOCITY IMPACT SENSITIVITY (.22, .30 and .50 cal.)

<u>Each Stage</u>

(1) 1 Subscale Prototype Test

(2) 1 Full-Scale Prototype Test

c. EFFECTS OF FIRE TEST

Gasoline Fire (2) Full-Scale Motor each Stage

These tests included laboratory, field, subscale motor, and full-scale motor testing at AFFTC.

The hazard classification test results are summarized in Table II.

TABLE II

OVER-ALL RESULTS OF
EXPLOSIVE CLASSIFICATION TESTS OF THE
PROPULSION SYSTEM FOR WEAPON SYSTEM 133A (MINUTEMAN)

REF: TW-543-5-61

TEST	RESULTS
A. Laboratory Tests	
a. Impact Sensitivity	TP-H1001 Propellant is more sensitive to impact than HMX (i.e. 89.45 vs 112.06 in. lb). Safe to handle - Class B.
b. Auto-ignition	1 hour 422°F ± 5°F 8 hour 405°F ± 10°F TP-H1001 is not supersensitive to temperature - Class B.
B. Field Tests	
a. Susceptibility to Detonation (1) Unconfined (60, 80, and 100°F) (3 1/2 in. dia x 6 in. ht) (2) Confined (60, 80, and 100°F) (3 in. dia x 7 in. lg 1/4 in. wall)	Propellant failed to detonate in all tests. All propellant samples ignited and burned except two from each of the 80 and 100°F conditions and 3 from the 60°F condition. All failed to detonate. TP-H1001 will not detonate under these conditions.
C. Full-Scale of Prototype Subscale Motor Tests a. Susceptibility to detonation	Both subscale motors were completely destroyed. TP-H1011 propellant did not detonate in TU-121 subscale case.

TABLE II (Cont)

(1) TU-121 Subscale Motor a. Test 1 b. Test 2	
(2) First Stage Subscale Motor TU-123-512.19 10,095.44 pound TP-H1002 Propellant	A detonation was not sustained in the MINUTEMAN propellant by the explosive energy from a 100 pound Composition B charge. Class B explosive and a Class 2 military classification-1500 pound TNT equivalency.
(3) First Stage Motor TU-122-1101.7 42,381 pound TRX-H609 Propellant	MINUTEMAN First Stage Motor will not sustain a detonation. Class B, military classification 2 1600 pound TNT or 4.85% total energy available.
b. High Velocity Impact Test (.30 Cal Rifle Bullet) (1) Susceptibility to Detonation a. Subscale TU-123-2101.01 9.764.69 pound Propellant .30 Cal Rifle fired from 80 ft. distance	Motor destruction by propellant ignition and subsequent pressure burst.
c. Effects of Fire Test First Stage Motor TU-122-307.6 (AVCOAT insulation) 41,525 pound TRX-H609 Propellant	At 122 seconds after 110 gallon gasoline was ignited a pressure burst occurred. At 143 seconds a second pressure burst occurred. Propellant burned approximately 7 minutes after ignition.

These results indicated that laboratory and field tests predicted that the MINUTEMAN propellant is properly classified as Class 2. The full-scale Detonation Susceptibility Test at AFFTC consisted of subjecting the full diameter motor to 100 pounds of Composition B detonated midway on the top side of the motor (Figure 7). The results indicated a TNT equivalent force of 1,500 pounds or approximately 3 1/2 percent of the total propellant.

Similar tests were conducted on the other stages of the MINUTEMAN Missile System with the end result that the classification and TNT equivalents were established as summarized in Table III.

TABLE III

MINUTEMAN HAZARD CLASSIFICATION

Stage	Propellant Weight, lb	Explosive Classification	TNT Equivalent, Percent	Total Explosive Weight, lb
I	45,000	2	5	1,500
II	12,500	2	20	2,500
III	3,500	9	100	3,500
			Total	7,500

Approximate TNT equivalent values for the MINUTEMAN Missile System have been established as previously discussed. The remainder of this paper will define future large payload missile systems and will discuss their TNT equivalent values and make comparisons with the MINUTEMAN System. In using this approach, maximum usage is made of the large amount of data generated from the MINUTEMAN program, which should result in a requirement for a smaller number of tests in future large solid propellant missile systems.

LARGE PAYLOAD MINUTEMAN AND 156 INCH ICBM SYSTEMS

Considerable interst is currently being generated by the Air Force and Industry in large solid propellant ICBM systems. The requirements for these systems is based upon the fact that the state-of-the-art in solid propellant rocketry has now reached a point where MINUTEMAN-type instant readiness ICBM systems can be developed to deliver payloads for 6,000 to 30,000 pounds. These systems can be installed in existing launch facilities at a low cost compared to existing systems with maintenance much lower than the current MINUTEMAN, ATLAS, or TITAN ICBM Systems.

Thikol has conducted contractual studies to define propulsion units for the Large Payload MINUTEMAN Missile System which has resulted in the recommendation of the system shown in Figure 8. This system consists of three stages and is much larger than the MINUTEMAN System. The Large Payload MINUTEMAN Stage I and II Motors will be 118 to 120 inches in diameter, with the Stage III Motor over 100 inches in diameter. Propellant weights for each of the three stages are 170,000, 90,000, and 80,000 pounds for a system total weight of approximately 270,000 pounds of propellant. This is greater than the Stage I MINUTEMAN propellant weight by a factor of five. Since the system is proposed for deployment in existing MINUTEMAN silos, it is necessary to review hazards associated with larger propulsion systems containing the same basic propellant as is presently contained in the Thiokol Stage I MINUTEMAN Motor.

Thiokol has been awarded a contract by the Air Force to demonstrate the feasibility of 156 and 260 Inch diameter propulsion systems. Since the 156 Inch

propulsion system is the largest system which can readily be transported to inland operational sites, this system is discussed in detail. Preliminary studies were conducted for an ICBM with a minimum payload weight of 30,000 pounds. This system design is presented in Figure 9. The system contains a high solids MINUTEMAN type propellant in all three stages, and the total propellant weight is approximately 1.5 million pounds. Potential sites for the Large Payload MINUTEMAN and 156 Inch ICBM are shown in Figures 10 and 11. It is proposed to obtain maximum utilization from existing facilities, therefore, hazards associated with these larger systems are compared to the MINUTEMAN System. Shipping modes for the Large Payload MINUTEMAN are shown in Figures 12, 13, and 14. For Large Payload MINUTEMAN, the segment weights are limited to 70,000 pounds, making possible modes of shipment including air, highway, and rail. The 156 Inch ICBM is limited to rail and water shipment.

The 156 Inch segment weights increase to approximately 250,000 pounds, and therefore, high capacity shipping equipment must be fabricated. The shipping support equipment being designed and procurred by Thiokol in support of the 156 Inch motor demonstration program is shown in Figures 15 and 16. Safety considerations involve the use of short sections of public highways, and primarily rail shipment. Since the MINUTEMAN System has not used rail as a primary shipping mode, a great deal of consideration will be given to the hazards associated with rail shipment of the large 156 Inch ICBM.

Both the 156 Inch and Large Payload MINUTEMAN Systems will be assembled in their launch facilities as shown in Figure 17. In this case, deployed missile systems should only be concerned with potential hazards to the missile emplaced in the silo.

The hazards associated with transportation of assembled MINUTEMAN missiles from the assembly and checkout buildings to the launch facilities are eliminated.

For preliminary R & D testing at the flight test facility launching, techniques similar to those used on TITAN II and SATURN V are considered. These will be in addition to a hardened silo for later silo launches at the flight test facility. The assembly and flight test firing of a 25,000 pound payload 156 Inch ICBM and a clustered 60,000 pound payload 156 Inch Space System are shown in Figures 18, 19, and 20. The final motor deployment being considered for large ICBM's is that of water deployment. The ground handling and transportation modes for the 120 and 156 Inch segments are identical to those used for ground deployment. However, in support of the water deployment mode (Figure 21), where the missile is actually assembled in a capsule and lowered to some depth under water, consideration will have to be given to the assembly of the missile and subsequent handling of the complete missile. Vertical assembly of the missile system is shown in Figure 22. Horizontal assembly would use existing high capacity dry dock facilities and then float the assembled missile to its deployment site.

The presently proposed development schedules for Large Payload MINUTEMAN and 156 Inch ICBM systems are outlined in Tables IV and V. From the schedules it is apparent that these systems will become available in the 1968 to 1972 time span. Due to the large size of these systems and the desire to use existing deployment sites, it is necessary to support the program development with hazard classification testing and to assess existing data to the point that this testing can be reduced to a minimum.

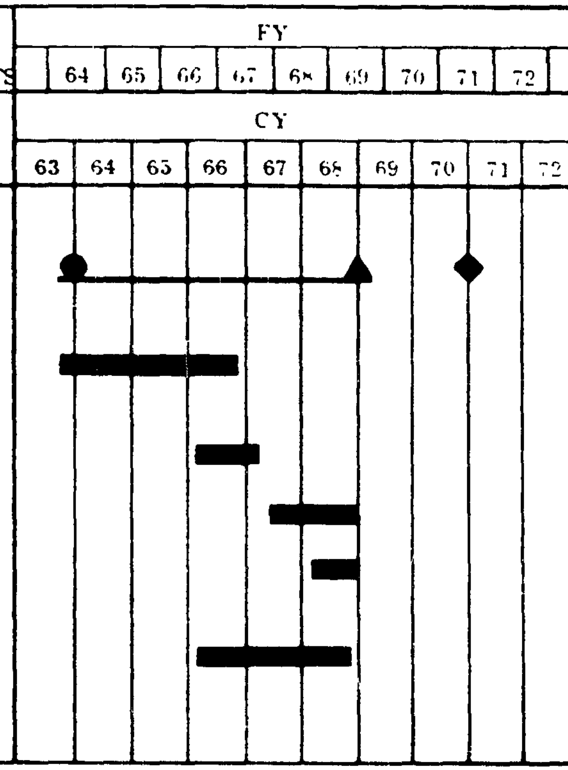
TABLE IV

CURRENT TECHNOLOGY	MOTOR REQUIREMENTS STAGE I	II	III	FY / CY	64 / 63	65 / 64	66 / 65	67 / 66	68 / 67	69 / 68	70 / 69	71 / 70	72 / 71	73 / 72
DEVELOPMENT OF 3-STAGE LPMM MOTORS														
41 MONTHS TOTAL TIME (CONTRACT GO-AHEAD TO IOC)														
DEVELOPMENT (INCLUDING FEASIBILITY)	16	8	16											
PFRT	6	6	6											
FLIGHT TEST (INCLUDING 2 SILO/FLIGHT FEASIBILITY)	32	32	32											
QUALIFICATION TEST	9	9	9											
MISCELLANEOUS TESTS (INCLUDING TRANSPORTATION, STORAGE, HAZARD CLASSIFICATION, ETC)	9	2	9											

● CONTRACT GO-AHEAD ▲ IOC - CURRENT TECHNOLOGY ◆ IOC - ADVANCED TECHNOLOGY

TABLE V

CURRENT TECHNOLOGY	MOTOR REQUIREMENTS STAGE I	II	III
DEVELOPMENT OF 156 INCH ICBM MOTORS			
66 MONTHS TOTAL PROGRAM TIME (CONTRACT GO-AHEAD TO IOC)			
DEVELOPMENT (INCLUDING FEASIBILITY)	8	5	8
PFRT	5	5	5
FLIGHT TEST	20	20	20
QUALIFICATION TEST	8	8	8
MISCELLANEOUS TESTS (INCLUDING TRANSPORTATION, STORAGE, HAZARD CLASSIFICATION, ETC)	5	1	5



● CONTRACT GO-AHEAD ▲ IOC - CURRENT TECHNOLOGY ◆ IOC - ADVANCED TECHNOLOGY

ADVANCED ICBM HAZARD CLASSIFICATION

Thiokol test results from the MINUTEMAN program and subsequent field test results on high solids propellants proposed for use in the high payload ICBM systems have indicated that the high solids MINUTEMAN-type propellants will be Class 2. However, the consideration of critical diameter and minimum booster size should be considered and may require limited full-scale testing.

The prime modes of inducing motor detonation of the missile systems would be from the high explosive trigger charge contained in the warhead. Since the warhead is installed after the missile is assembled in the silo, the hazard classification considerations confine themselves largely to the assembled missile in the launch facility. Since the warhead and explosive trigger charge is installed in the vicinity of the Stage III Motor, the propagation of detonation would be from the warhead through Stage III and subsequently into Stage II and I, for both Large Payload MINUTEMAN and 156 Inch ICBM. Other modes of inducing a detonation would be from fire, impact, or premature launch of the vehicle. Another consideration would be the dropping of the assembled missile or individual segments. MINUTEMAN hazard classification test results indicate that dropping this propellant system would not cause detonation, and at worst, would only cause a fire and pressure burst from the breakup of the propellant. Based upon these considerations, Table VI outlines the classification and TNT equivalents of Large Payload MINUTEMAN and 156 Inch ICBM assembled missiles.

TABLE VI

LARGE PAYLOAD MINUTEMAN AND 156 INCH ICBM
TNT EQUIVALENT AND CLASSIFICATION

Stage	Propellant Weight, lb	Classification	TNT Equivalent Percent	Equivalent TNT Weight, lb
I	170,000	2	0	0
II	90,000	2	0	0
III	30,000	2	5	1,500

Stage	Propellant Weight, lb	Classification	TNT Equivalent Percent	Equivalent TNT Weight, lb
I	960 000	2	0	0
II	400,000	2	0	0
III	90,000	2	5	4,500

The review of the data in Table VI indicates that the total TNT force for Large Payload and 156 Inch ICBM are 1,500 and 4,500 pounds, respectively. These numbers are considerably lower than the 7,500 pound TNT equivalency currently assigned to the MINUTEMAN Missile System, therefore, the MINUTEMAN siting would be compatible with both Large Payload MINUTEMAN and 156 Inch ICBM propulsion systems.

As previously emphasized, Thiokol has made strong recommendations that future ICBM's have all Class 2 propulsion systems. Thiokol studies conducted to date using high energy propellants with potential Class 9 hazard assignments would effect a TNT equivalent value for the missile systems which would not be compatible with current siting. For example, if the Large Payload MINUTEMAN and 156 Inch ICBM systems listed in Table VI has Stage III motors which contained Class 9 propellant.

the TNT equivalent values would be a minimum of 30,000 and 90,000 pounds for Large Payload MINUTEMAN and the 156 Inch ICBM, respectively. Both of these numbers are unacceptable compared to the presently assigned value of 7,500 pounds for MINUTEMAN, and force the conclusion that with Class 9 propellant future Large Payload ICBM's systems would require new siting.

RECOMMENDED FUTURE TESTING

Since the hazard problems associated with Class 2 propellant Large Payload ICBM's do not appear to be greatly different from those encountered in current missile systems, only limited hazard classification testing should be required.

The large size and resulting cost of the completely assembled large payload missile systems precluded extensive full-scale hazard classification testing. Assuming that propellants are carefully screened by laboratory and field testing prior to their incorporation into the large motors, the hazards associated with these larger motors will be comparable with those associated with the smaller systems such as MINUTEMAN. Air Force regulations at Cape Canaveral, Vandenberg, and over-all Air Force requirements per TO-11A-1-47 require minimum demonstration testing prior to use of the new missile system. In order to keep the cost to a minimum, and yet comply with safety requirements, Thiokol recommends limited full-scale testing. Hazard testing is summarized as follows:

Preliminary Propellant Testing

Initial propellant hazard classification testing will be conducted in accordance with the Explosive Hazard Classification Procedure outlined in the U.S. Air Force Technical Order TO-11A-1-47, dated 31 Jul 1962. The tests outlined under Test Phase I and Test Phase II will be conducted which include the laboratory development

tests on small propellant samples, detonation, ignition, thermal stability, impact sensitivity and differential thermal analysis. Tests covering the propellant development phase include critical diameter, card gap, external heat, and bullet impact tests using propellant samples up to 8 inches in diameter.

Propellant Web Testing

The tests outlined in Test Phase I and II are limited to a maximum charge size of 8 inches in diameter and the tests outlined in Phase III require the use of full-scale motors. An intermediate test is proposed which will evaluate the propellant detonation hazards of the full-scale motor in a charge size greater than 8 in. diameter, but smaller than the full-scale motor. This test will use a charge diameter equivalent to the propellant web thickness of the 120 in. diameter Large Payload MINUTEMAN and the 156 Inch Diameter ICBM which has web thicknesses of 32 and 48 inches, respectively. The propellant charges will have a length to diameter ratio of five. The explosive boosters, either Compsotion B or 50/50 pentolite, will have an L/D of 1 and be the same diameter as the propellant charges. If a sustained detonation is not produced, the full-scale detonation test would not be required to establish detonation hazards since the web thickness is a controlling parameter when considering detonation hazards of propellant grains. Each test would be instrumented with velocity gages to measure the reaction wave velocities and transients and air over pressure and seismic instrumentation to measure the equivalent explosive forces. The sample will be conditioned to the maximum temperature expected during missile operation prior to test. A sketch of the proposed test setup is shown in Figure 23.

Full-Scale Testing

The 156 Inch Diameter Motor will be tested to verify that the critical diameter has not been exceeded in going to the largest diameter propulsion unit which can be shipped by rail. TO-11A-1-47 outlines a test whereby a 2 by 2 inch 50/50 pentolite explosive charge is placed inside the motor chamber against the propellant grain to determine the classification of the motor. Thiokol has evaluated the effects of such a charge placed on the propellant grain and predicts that no problem would be encountered in running such a test. However, since the explosive contained in the missile warhead is considerably larger than the 2 by 2 pentolite charge, it is recommended that a 100 lb pentolite charge be used for detonation testing of all stages. This is the largest charge of explosive to which the motor could be subjected in transportation, assembly, or operational use.

CONCLUSIONS

Large Payload ICBM's have been reviewed and based upon an assumption that Class 2 propellants will be used in the motors, TNT equivalents for the Larger ICBM's appeared to be lower than that for the MINUTEMAN System.

In order to comply with military safety regulations and to assure that critical diameters have not been exceeded in going to the larger diameter propulsion systems, it is necessary to conduct a minimum series of hazard classification tests. Such a minimum series of testing has been recommended by Thiokol Chemical Corporation. Since other propulsion contractors, systems' contractors, the Air Force, and the Armed Services Explosives Safety Board are involved in making final explosive classification assignments and determining acceptable missile siting. Thiokol

recommends that a joint team be established to set up details, and criteria for future hazard classification testing associated with ICBM's up to the 156 Inch diameter classification.

This joint team should assess the probability of:

(1) Occurrence of incidents,

(2) Sources of damage, and

(3) Acceptable risk, which can be safely assumed.

Based upon this complete review, the joint team should further review the recommendations made by the individual team members, military hazard classification test procedures, such as TO-11A-1-47, and results of previous solid propellant hazard classification test obtained on the MINUTEMAN program. A test plan should be formulated which will result in the proper assignment of hazard classification to the large solid propellant rocket motors and ICBM systems.

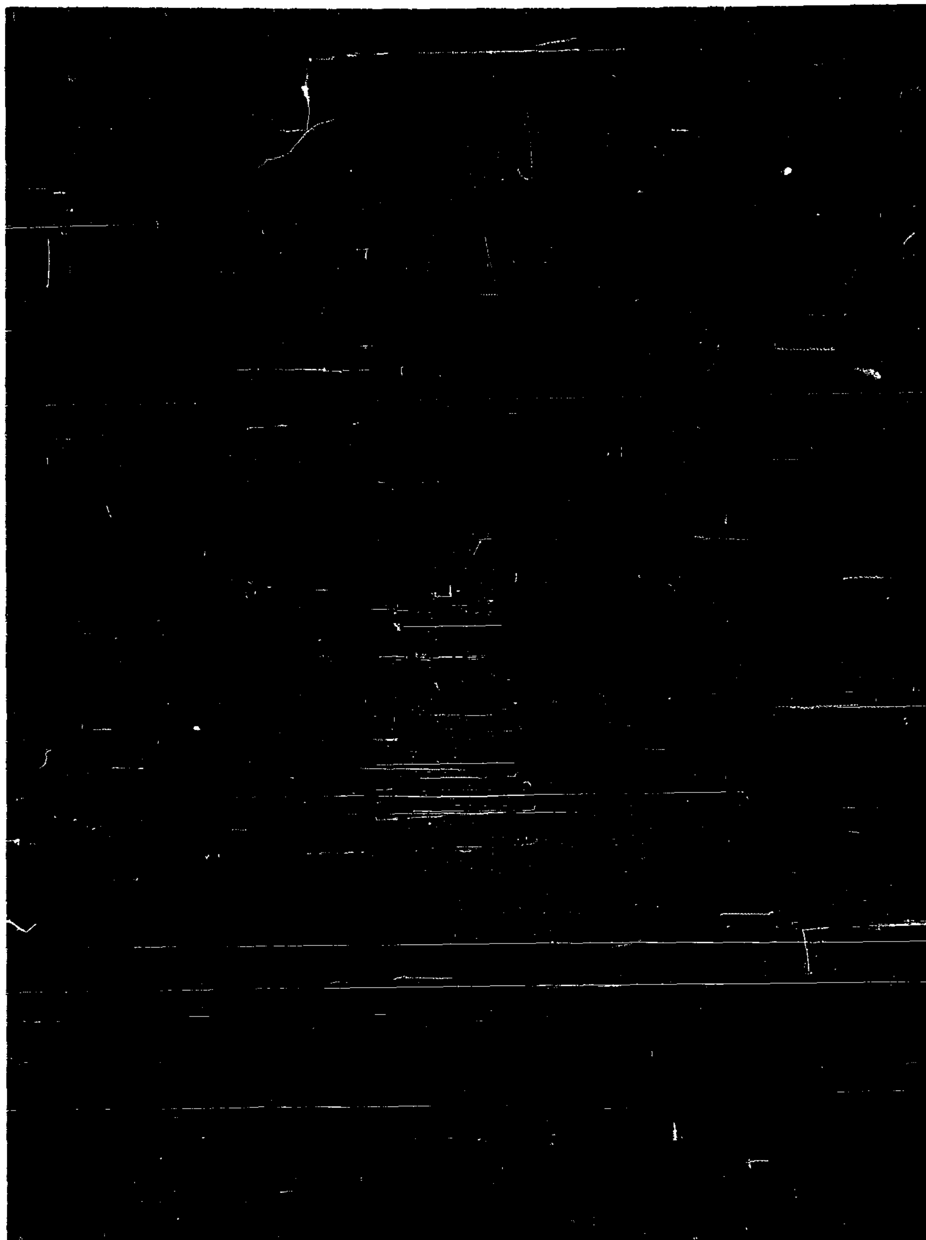


Figure 1. MINUTEMAN Motor Design Characteristics

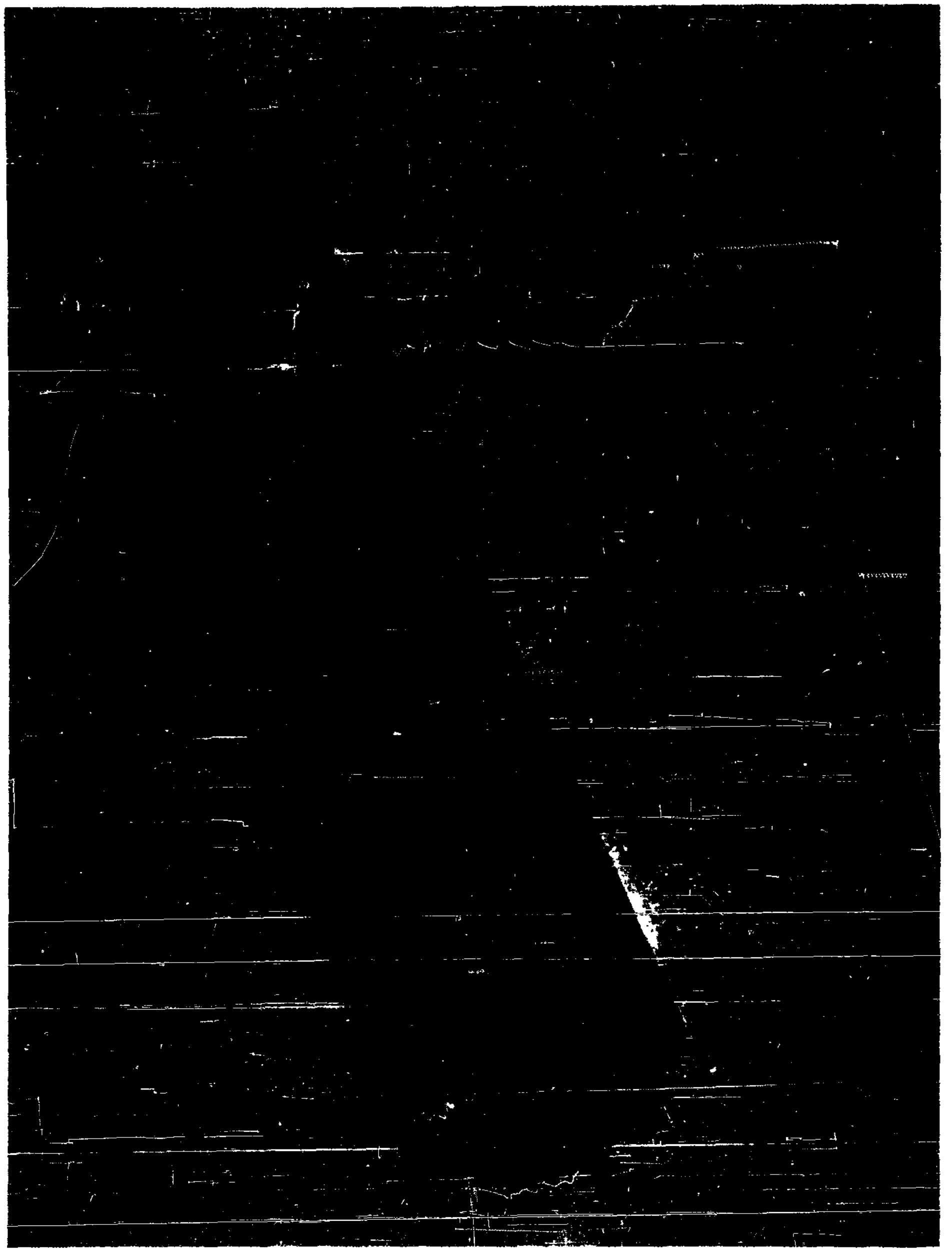


Figure 2. Cutaway Drawing of Stage I Motor

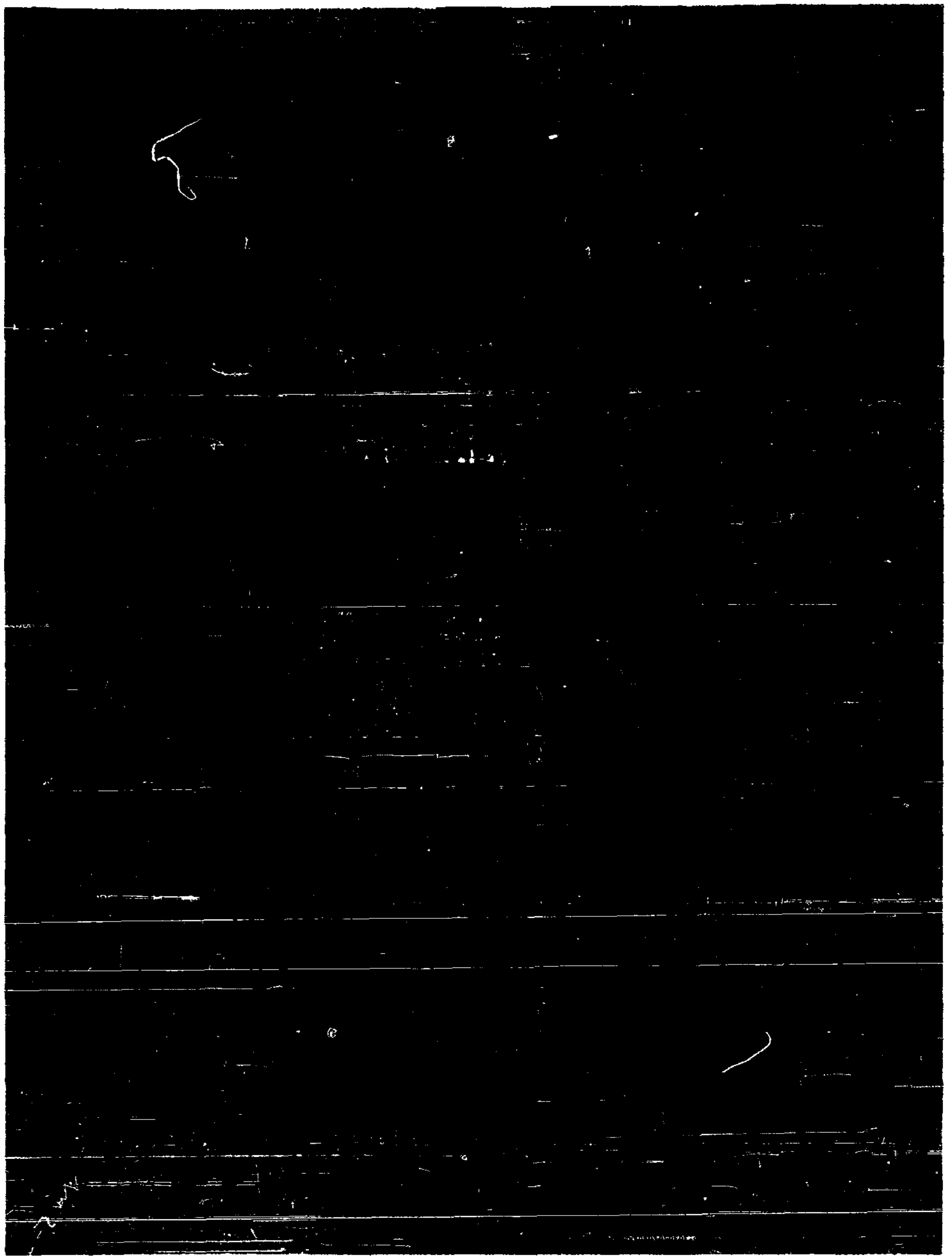


Figure 3. MINUTEMAN Highway Transporter

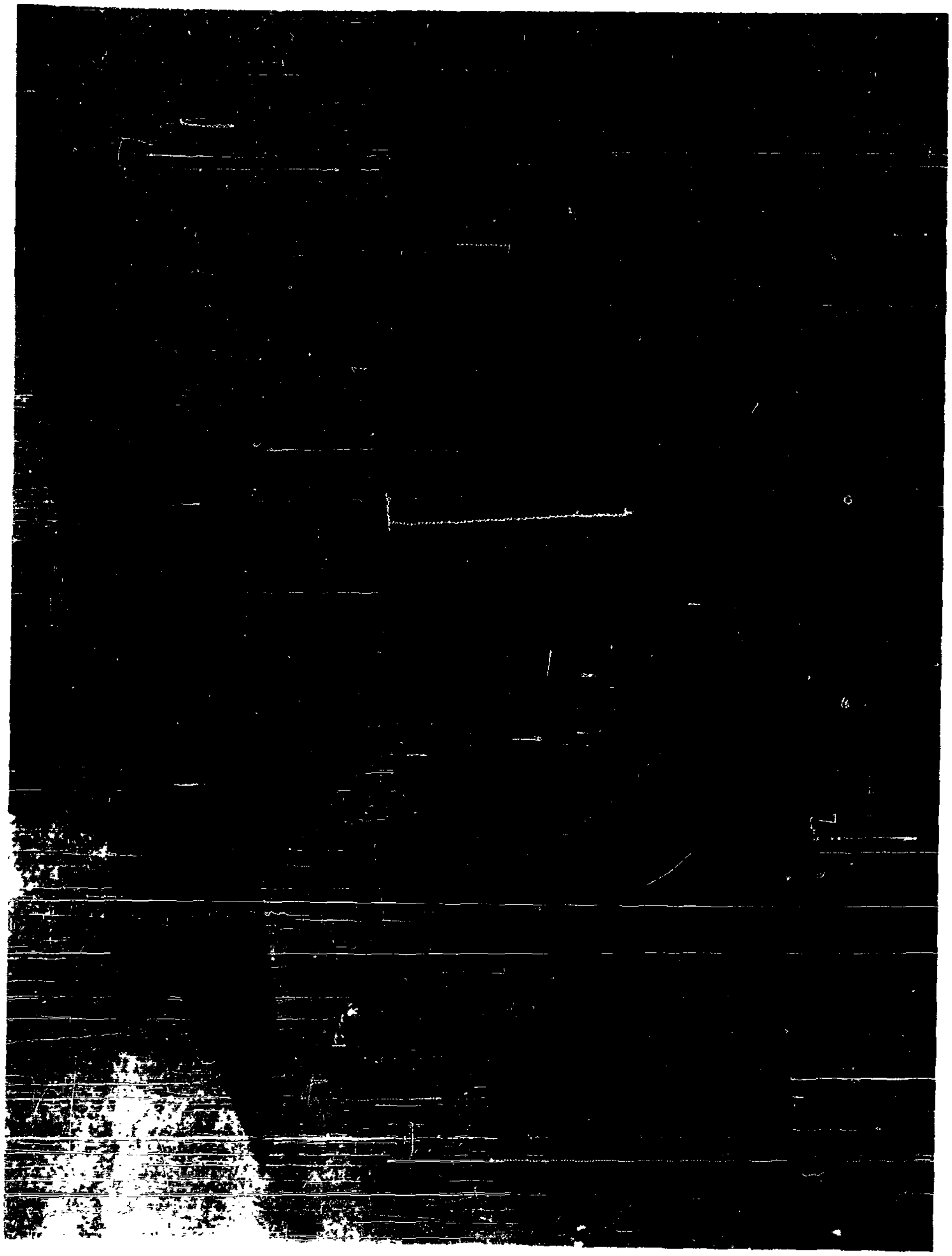


Figure 4. MINUTEMAN Air Transporter

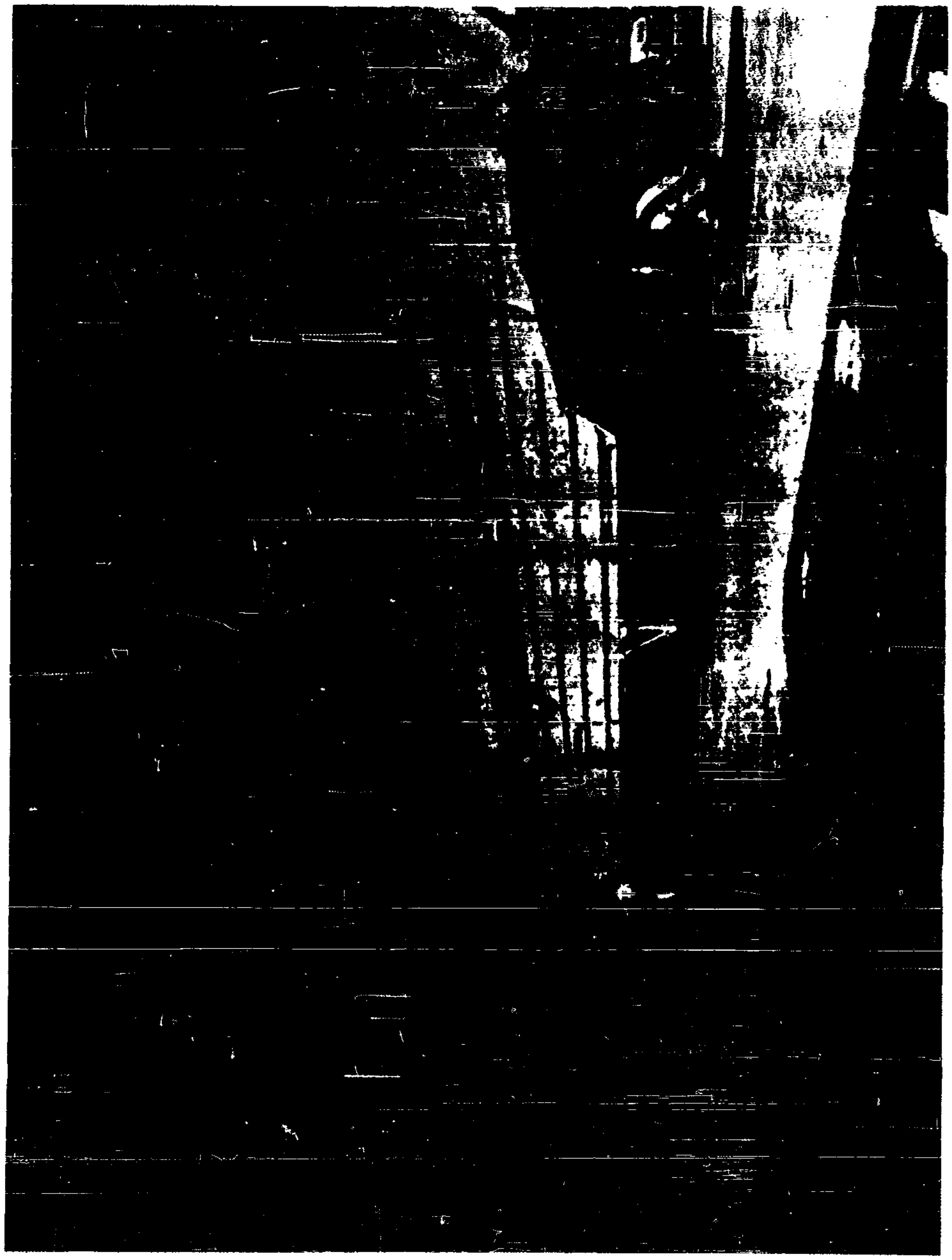


Figure 5. MINUTEMAN Transporter Erector

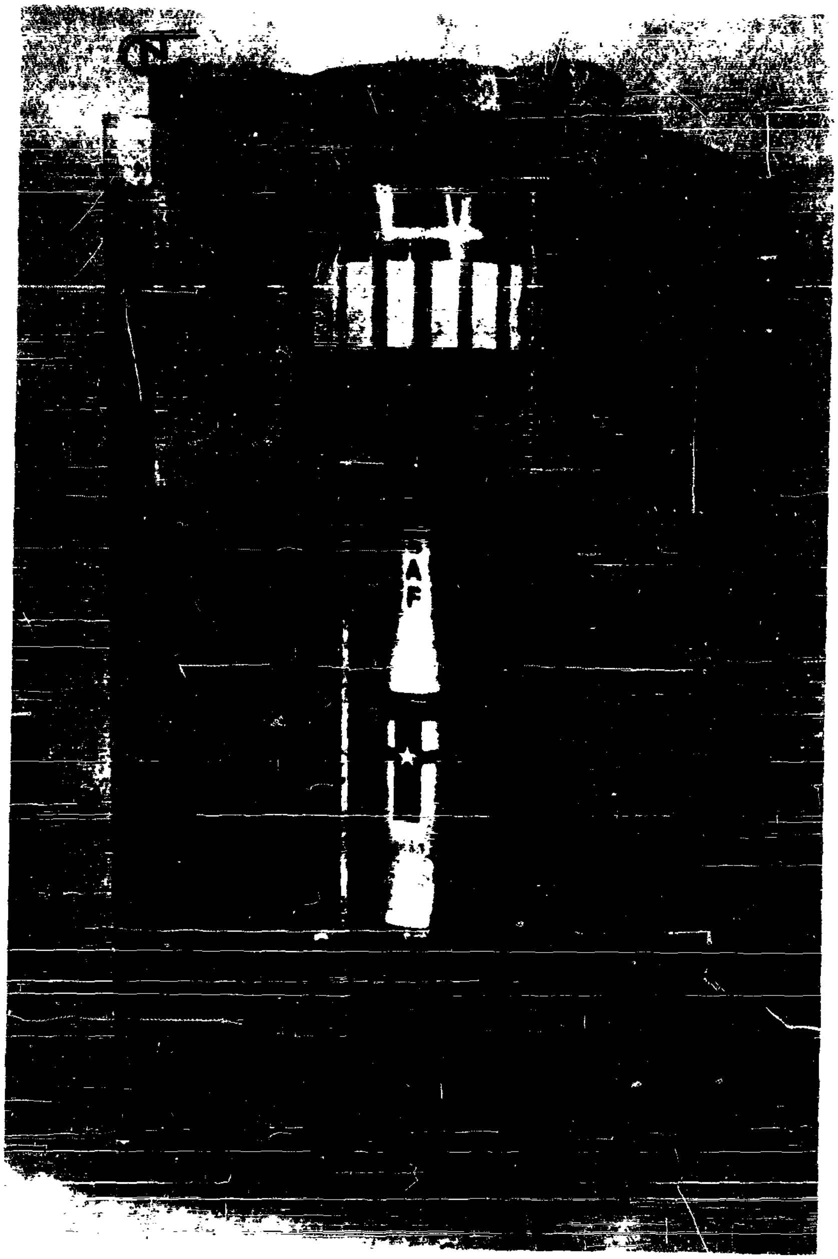
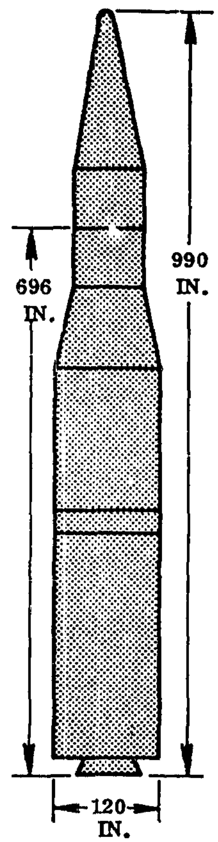


Figure 6. MINUTEMAN Launch Facility

Figure 7. Full-Scale Testing at AFFTC of the Full Diameter Motor



	STAGE I	STAGE II	STAGE III
MOTOR PERFORMANCE			
TOTAL IMPULSE (10^6 LB-SEC)	44.86	24.43	10.36
DURATION (SEC)	69.4	70.0	97.7
THRUST (LB)	646,400	348,000	106,000
WEIGHT SUMMARY			
INERT WEIGHT (LB)	18,900	11,100	3800
PROPELLANT WEIGHT (LB)	170,000	89,500	35,900
STAGE TOTAL WEIGHT (LB)	188,900	100,600	39,700
PROPELLANT MASS FRACTION	0.90	0.89	0.90
TRAJECTORY PERFORMANCE			
RANGE (N-MI)		6500	
PAYLOAD (LB)		8100	
MAX. "q" (PSF)		1660	
MAX. ACCELERATION (g)		3.72	
LIFT-OFF WEIGHT (LB)		337,300	

Figure 8. Current Technology of Large Payload MINUTEMAN System

	STAGE I	STAGE II	STAGE III
MOTOR PERFORMANCE			
TOTAL IMPULSE (10^6LB-SEC)	254.8	67.8	23.0
DURATION (SEC)	94.0	94.0	100
THRUST (10^6LB)	2.83	.721	.240
WEIGHT SUMMARY			
TOTAL INERT WEIGHT (LB)	124,800	31,200	8,900
TOTAL PROPELLANT WEIGHT (LB)	945,900	241,700	80,000
TOTAL STAGE WEIGHT	1,070,700	272,900	88,900
PROPELLANT MASS FRACTION	0.88	0.88	0.90
TRAJECTORY PERFORMANCE			
RANGE (N. MI)		6500	
PAYLOAD (LB)		30935	
MAX "Q" (PSF)		1730	
MAX ACCEL (G)		4.8	
TOTAL LIFT-OFF WEIGHT (LB)		1,461,900	

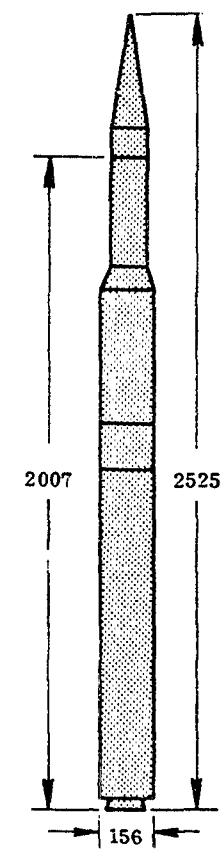


Figure 9. Current Technology of 156 Inch ICBM

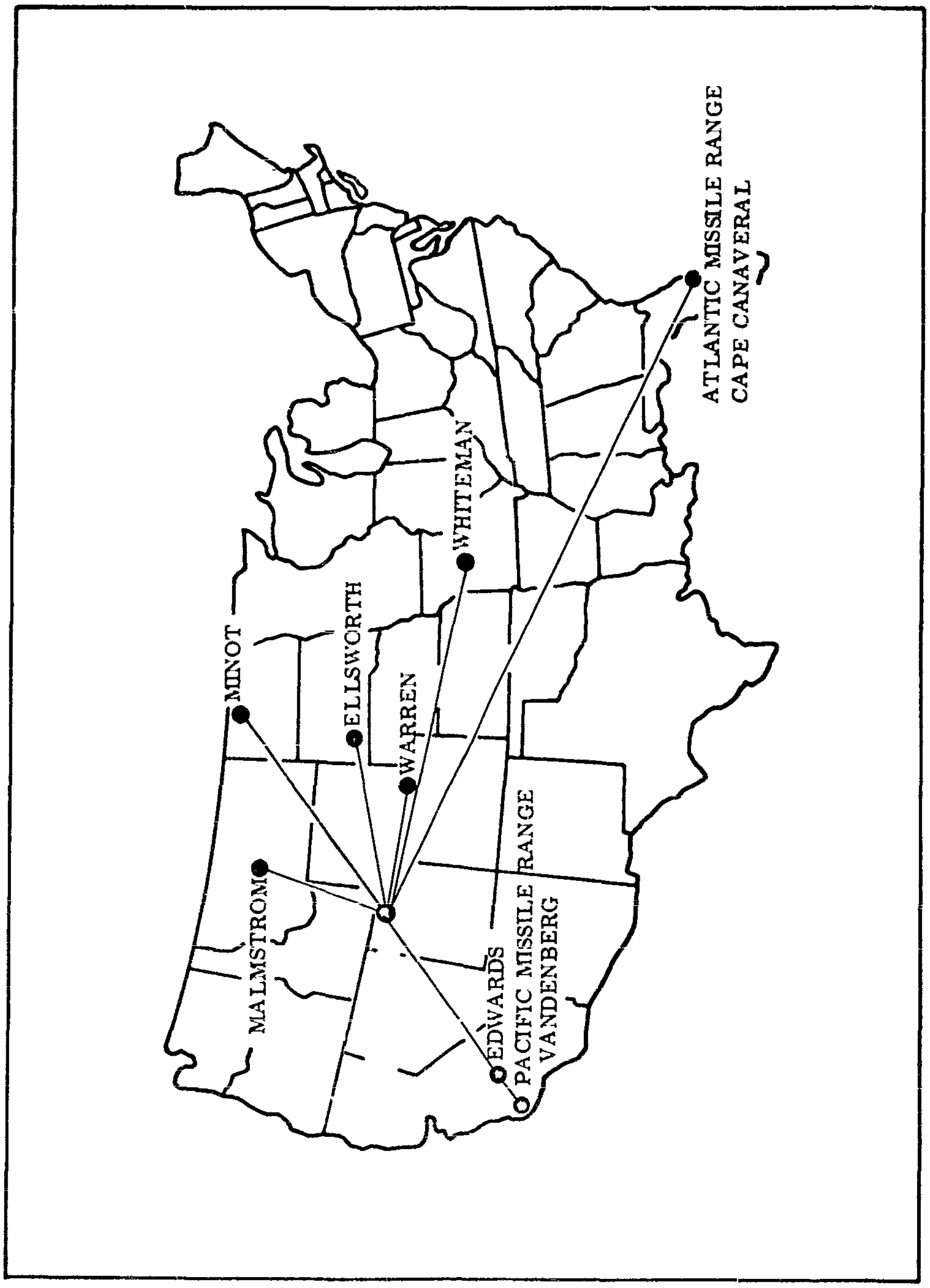


Figure 10. Potential Sites for Large Payload MINUTEMAN

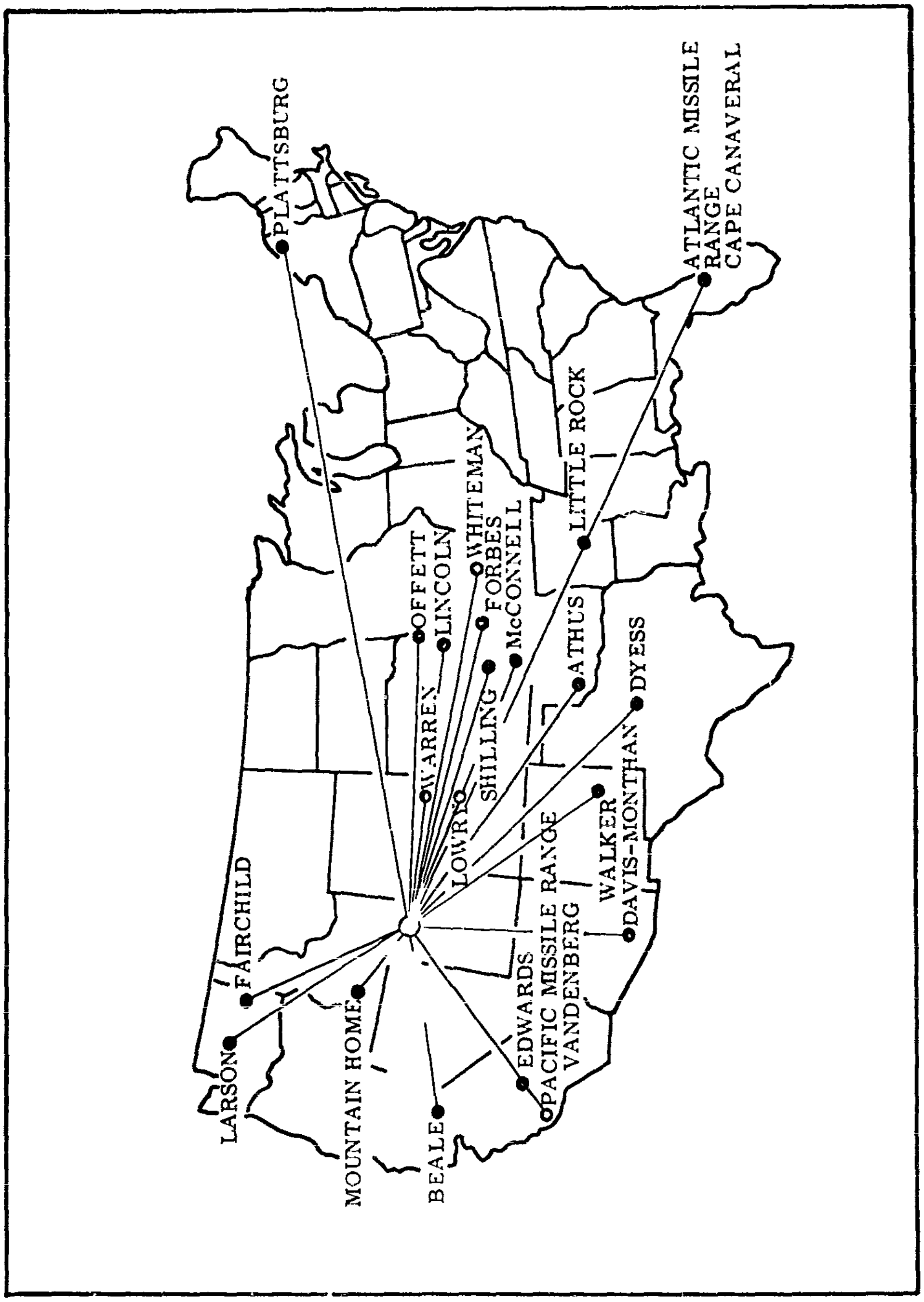


Figure 11. Potential Sites for 156 Inch ICBM

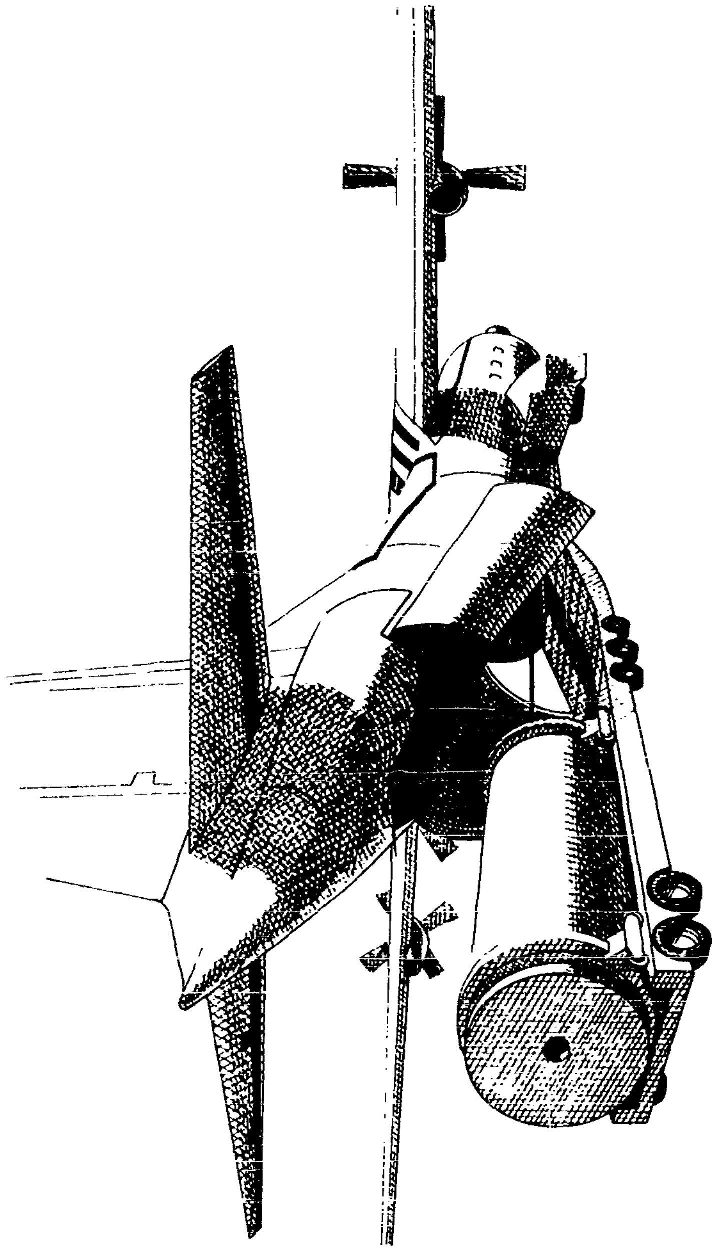


Figure 12. Air Shipping Mode for Large Payload MINUTEMAN

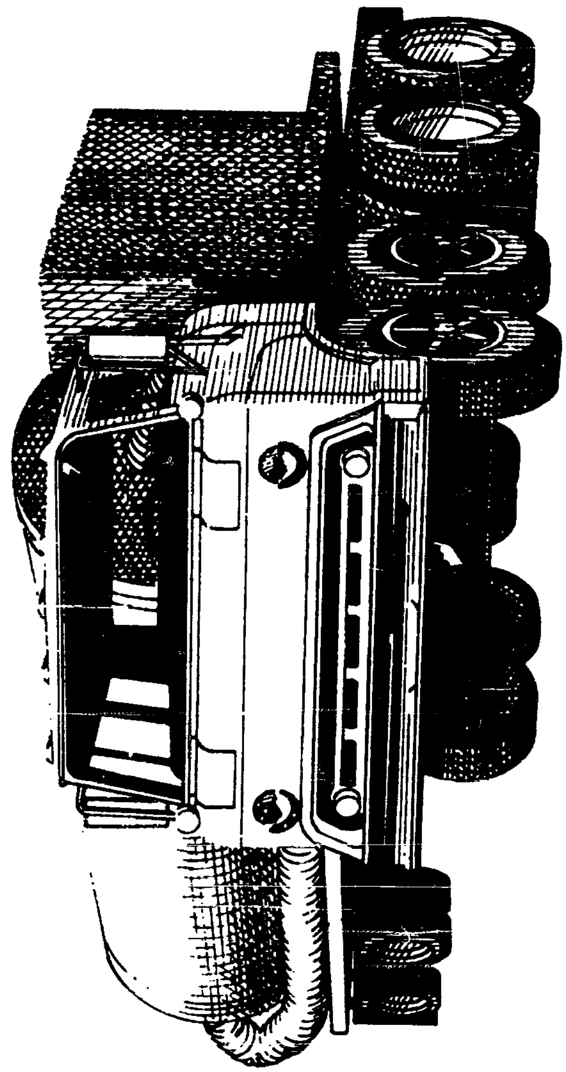


Figure 13. Highway Shipping Mode for Large Payload MINUTEMAN

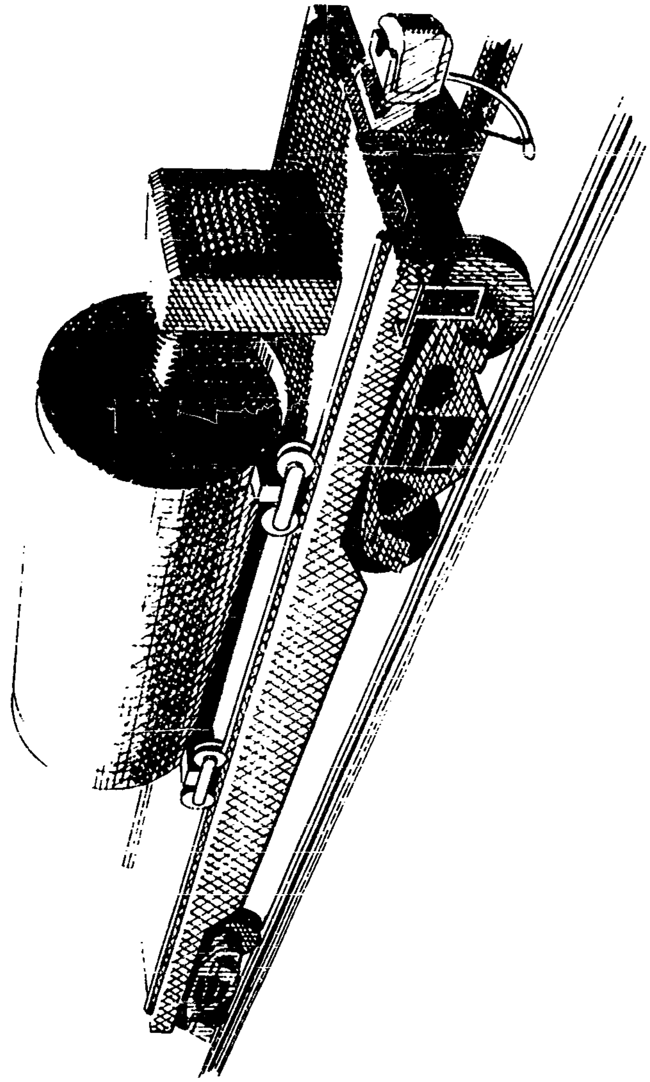


Figure 14. Rail Shipping Mode for Large Payload MINUTEMAN

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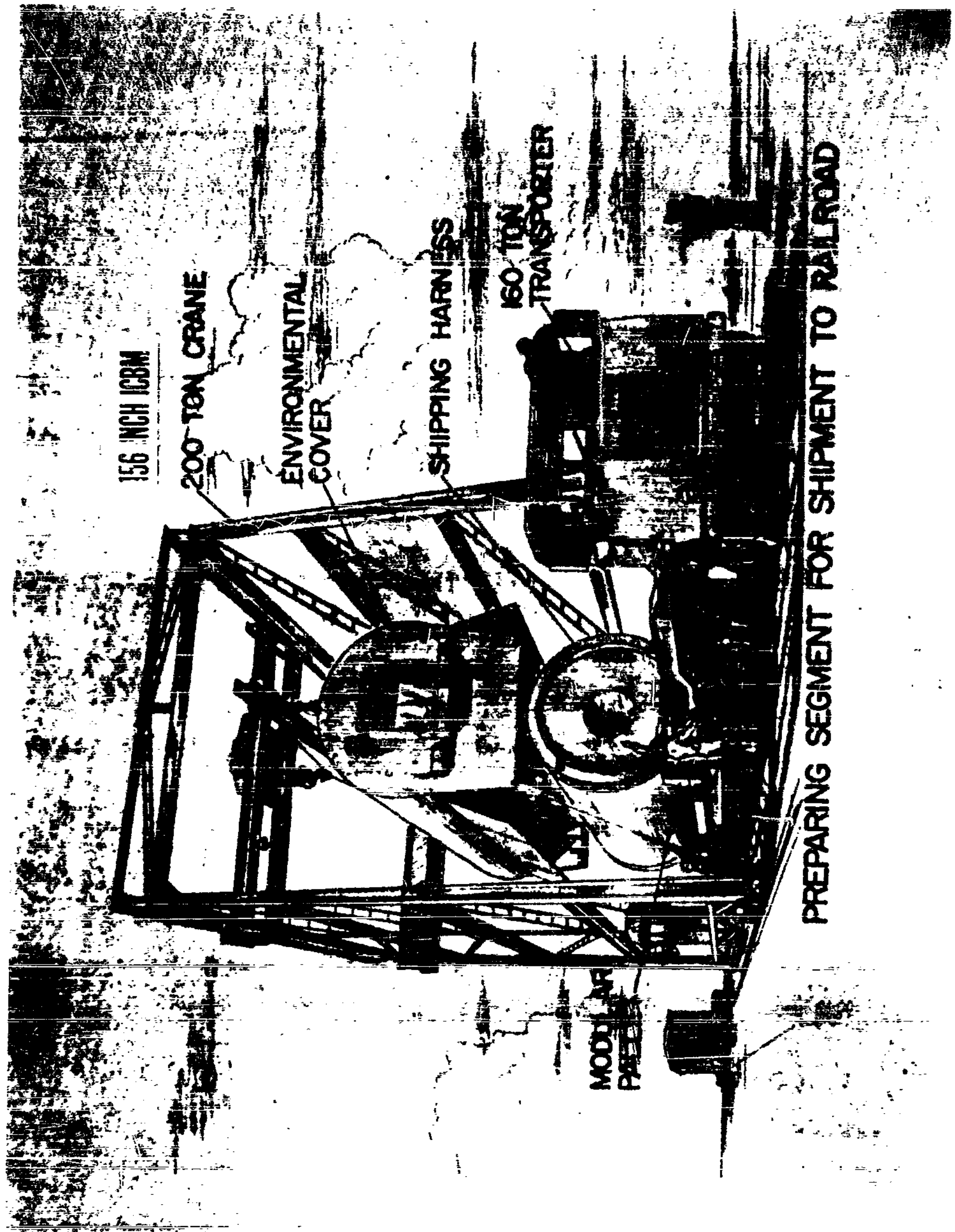

Figure 15. Rail Shipping Support Equipment for 156 Inch ICBM

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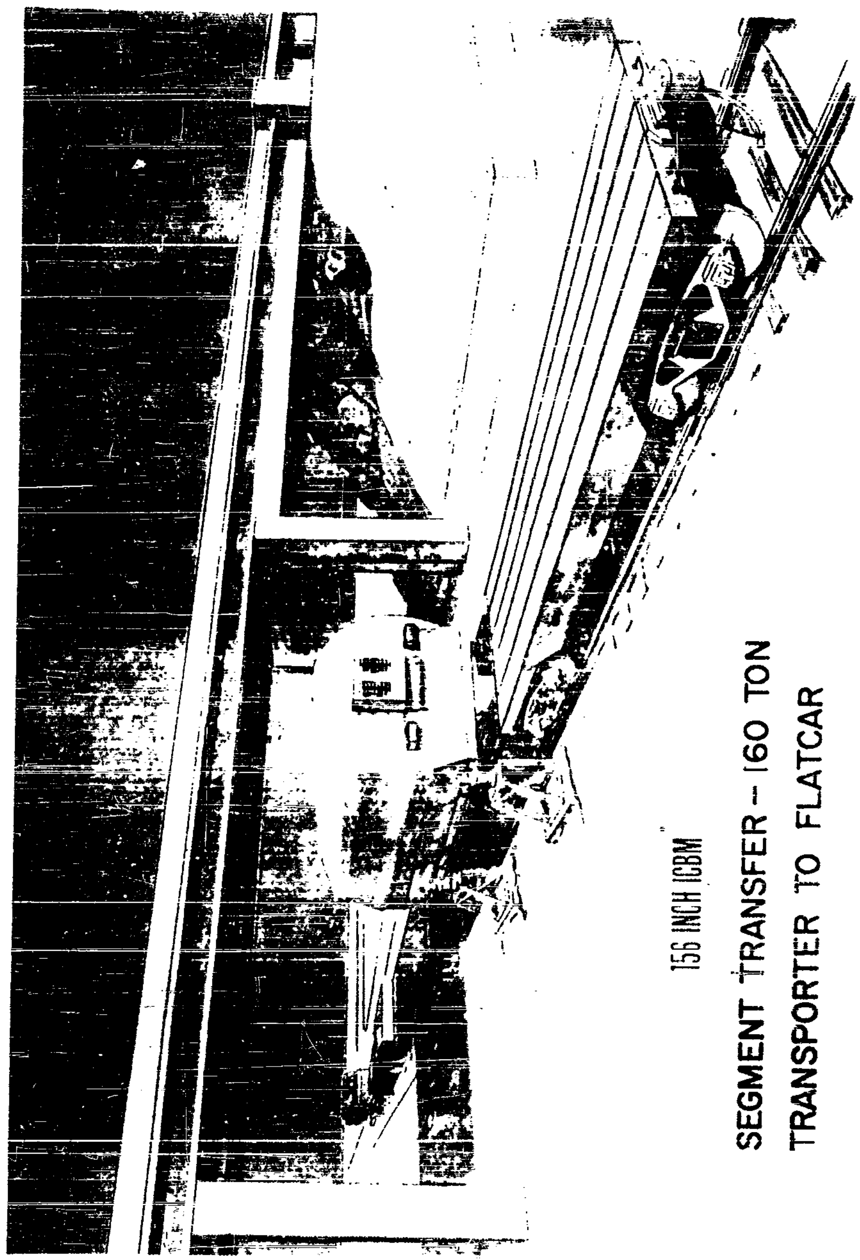

Figure 16. 156 Inch ICBM Segment Transfer

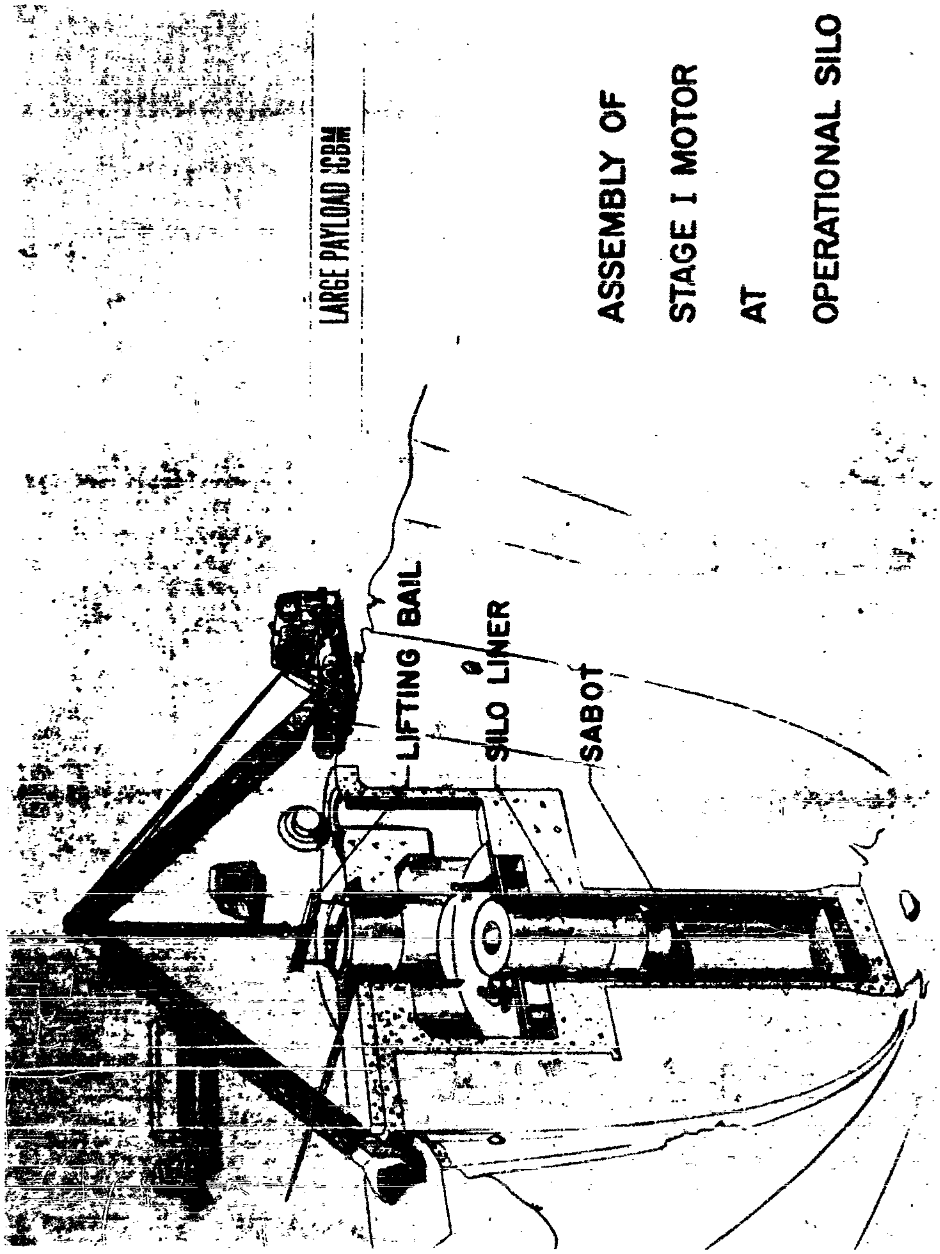

Figure 17. Large Payload ICBM Launch Silo

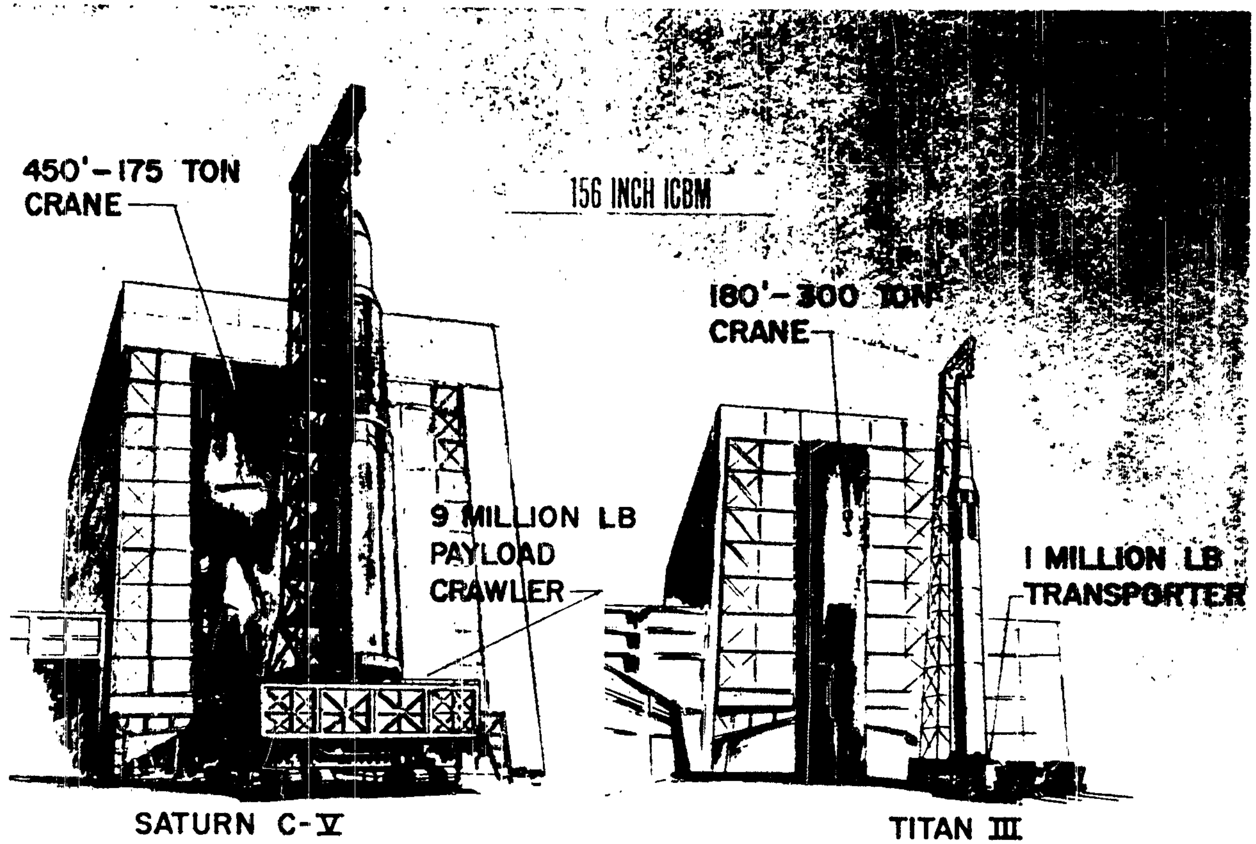

Figure 18. Assembly and Flight Test Firing of 25,000 Pound Payload 156 Inch ICBM and Clustered 60,000 Pound Payload 156 Inch Space System

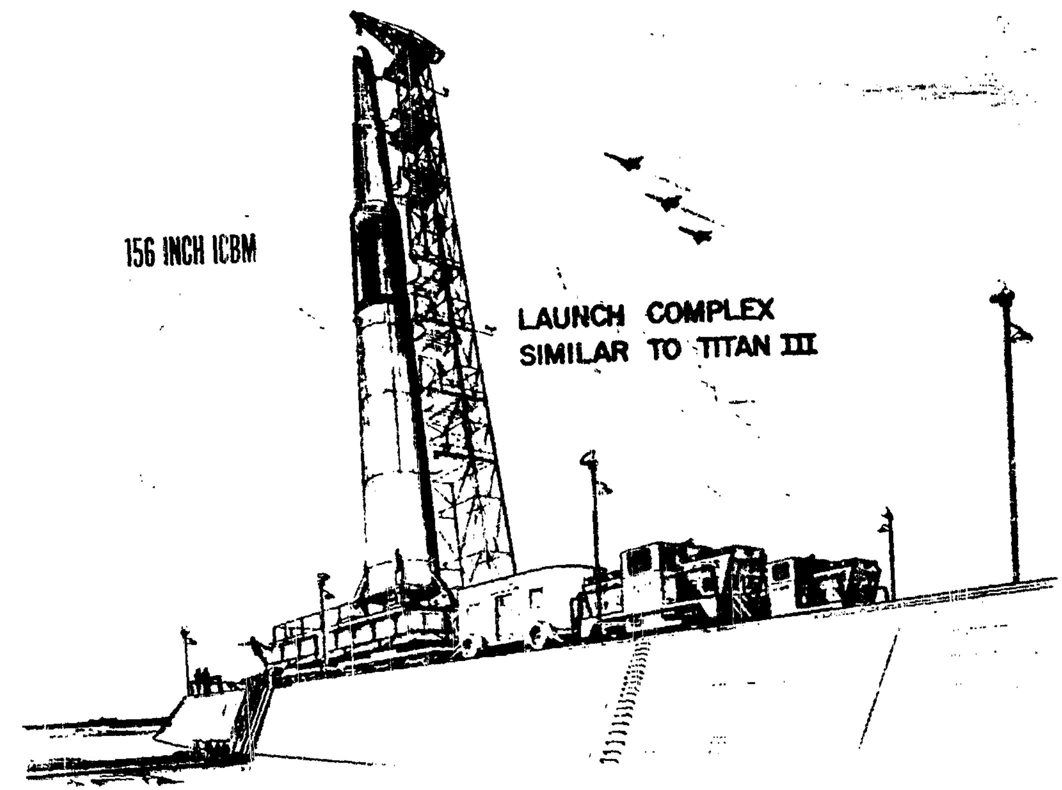

Figure 19. Assembly and Flight Test Firing of 25,000 Pound Payload 156 Inch ICBM and Clustered 60,000 Pound Payload 156 Inch Space System Using Launch Complex Similar to TITAN III

Figure 20. Assembly and Flight Test Firing of 25,000 Pound Payload 156 Inch ICBM and Clustered 60,000 Pound Payload 156 Inch Space System Using Launch Complex Similar to SATURN C-5

Figure 21. Water Deployment Mode for 156 Inch ICBM

Figure 22. Vertical Assembly of 156 Inch ICBM

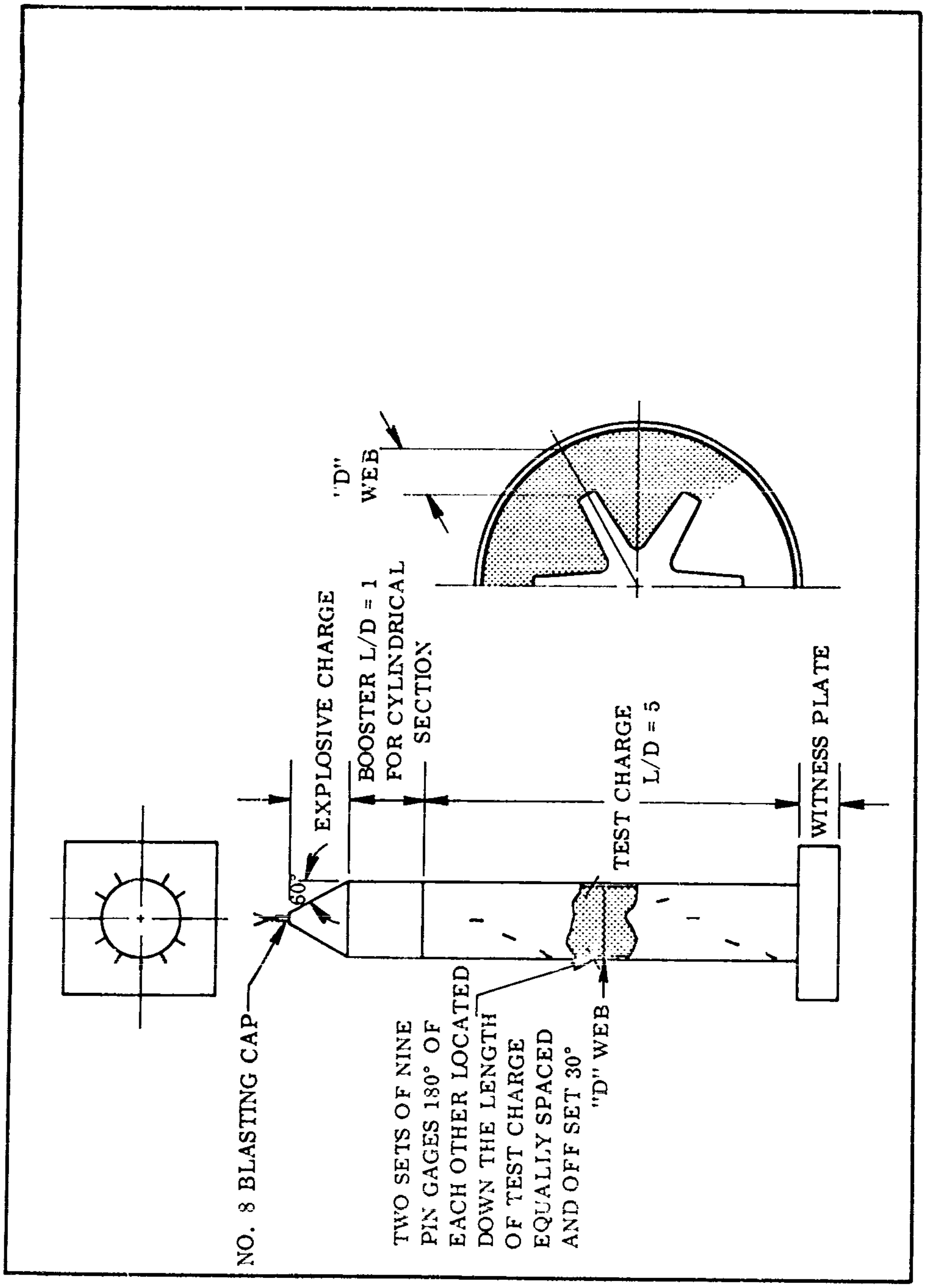

Figure 23. Detonation Velocity

Mr. Ely: Is it your current intent to put the large payload Minuteman in the present Minuteman site?

Mr. Nance: That's right. That's the way the thing is being formulated and studied and this assumes that the hazard classification of the individual motors in the total system would be equal to or less than that of Minuteman.

Mr. Hamilton: You deal with the TNT equivalents on the basis that the damage to anything surrounding the silo would be from your blast overpressures. This of course is only one of the vehicles for doing damage to surrounding areas.

Mr. Nance: That's right.

Mr. Hamilton: Have you considered the effect of fragments?

Mr. Nance: Yes, this has been considered. We used as an example, the Titan II incident at Vandenberg, when we formulated preliminary data and ran some other computer studies at the Boeing Co., I can't say they don't anticipate the hazard problem, at this point and time we think will probably be of a more real consideration than the TNT equivalent.

Mr. Settles: I don't want to depreciate what you said at all and I'm perfectly willing for you to be optimistic about it; however, I think as you try to establish a hazard classification on all your units regardless of the size, there is a minimum you're going to have to comply with the joint Services hazard classification requirement. If I'm mistaken in this, I need to be educated and I'll appreciate it if somebody will do that. However, the joint Services requirements I think were not fully complied with in classifying the Minuteman. For instance, when you ran your test on the Stage III, as I understand it, the booster was on the outside of the case so any TNT equivalencies that were developed by that method would not be realistic and would not comply with joint services hazard classification tests.

Mr. Nance: That's true. We think the joint services hazard classification test should be followed as far as you can afford to follow it and the test there of course is inside of the grain. I'm talking about a monetary amount here, the number of tests, etc. We've looked at that, we feel that that is within the realm of what we can afford to follow. In my paper I have indicated specifically that we should follow that. We do think, however, that the booster size spelled out in that is somewhat small and we think it would leave room for question, but perhaps we should use a larger booster.

Mr. Settles: You would have no trouble with Phase I and Phase II. Phase III which is what you're concerned about, gets to be a little more critical I'll grant you, but if you don't go full scale then it would seem as an alternative, the only alternative, go back to the committee, the Ball Committee, the one that Dr. Van Dolah and Dr. Price participated in, and use the suggestions that were given there unless something better is developed subsequently.

Mr. Nance: I can only say that I agree and we're very much in favor of getting some full scale testing going on the 156" diameter size as soon as the ground work can be layed.

Mr. Bishoff: I understand on your full scale test of the first stage of the Minuteman you did get one to go high order. Would you discuss that please.

Mr. Nance: You're data is erroneous. The only indication of high order detonation was from Mr. Ullian yesterday. We could not get one to go high order, they did get one to go high order as a Stage III.

Mr. Ullian: I'd like to comment on some of the things you said. I don't believe them and I don't think you do. I notice when you talk about running tests on critical diameter, you picked the smallest diameter web where the star grain reaches an apex, instead of the large diameter down the valley. I question why.

Mr. Nance: Actually that is an honest error. It is going to be a cylindrical grain preparation we hope so that problem will be eliminated and we'll just take the diameter of the cylinder.

Mr. Ullian: My second question concerns all testing to be static in nature and from our experience as you mentioned it was your first stage, I didn't tell them it was the Thiokol first stage, I'll let you do that. We get entirely different results than you're predicting or that was predicted from the static tests that were run in the hazard classification. I realize that at your operational sites you plan not to launch these except in anger, maybe you'd be willing to take a greater risk, but since you're going to have to launch these things from national ranges to prove out the system you're going to have to consider other than static test. I think that's going to have to be a must, personally.

Mr. Nance: In the dynamic type testing that you could conceivably run that would approximate the results, your opinion on Minuteman would appear that the only way you can get that is to drop it from 10 or 15,000 feet in the air.

Mr. Ullian: I think some of the things Dr. Ball's group suggested are going to have to be done. How in the dickens do you all come up with the conclusion that if you get more and more propellant the TNT equivalency or whatever you want to call it, the hazard level as such goes down.

Mr. Nance: That was not the conclusion.

Mr. Ullian: I'm sure it isn't.

Mr. Nance: The conclusion was that if you have an all Class 2 system as compared to a Class 9, Class 2 mixture system, the numbers come out so that the total energy is lower because you've eliminated the Class 9 propellant. I know the Air Force is very interested and I know that Hercules is very interested in reducing that classification and if our propellant in fact is mis-classed as 2, we are very interested in lowering that and I'm not disagreeing with anything you've said really.

Mr. Saffian: You had a chart up there where you showed one motor and one of the larger motors and you showed the approximate TNT equivalent and two zeroes. As I understood your presentation that was based on the assumption that you would not propagate to those stages for which you have indicated zero TNT equivalents?

Mr. Nance: Yes. We're saying the detonation would fade out from the Stage III that's initiated there by the most probable source which would be the warhead.

Mr. Saffian: Even tho you don't sustain a stable detonation in those stages for which you have found a zero equivalent, you'll get fire contribution, you don't have to sustain a stable detonation on that mass of propellant.

Mr. Nance: You get contribution in the form of fire and smoke and probably debris, etc. that has to be considered separately.

Mr. Saffian: I think it will be more than that, I think it will be TNT equivalent.

UNCLASSIFIED

QUANTITY-DISTANCE REQUIREMENTS FOR LARGE AMOUNTS OF SOLID PROPELLANTS

by
R. G. Perkins
Armed Services Explosives Safety Board

As many of you recall from the 1962 Seminar at Langley, I then discussed briefly some of the problems encountered by the Work Group to Study Quantity-Distance Requirements for Large Solid Propellant Motors. In this discussion, it was pointed out that some of the available information indicates serious gaps in our knowledge, particularly with respect to the so-called high explosive equivalency factors which are widely used to assess the potential of these motors. Unfortunately, I cannot honestly say that the review of the subject in the ensuing year has really lessened these problems. It is not unreasonable to state, actually, that some of the doubts are more widespread and serious than they were a year ago.

A standard for the separation of Class 2 burning-type propellants from inhabited buildings or other targets requiring this degree of protection of eight times $W^{1/3}$ has been agreed upon by the Work Group and was accepted by the Board. This permits extrapolation of the Class 2 tables to any reasonable amount that seems likely to be required in the future. For those materials which detonate or "partially detonate" -- I use the term "partially detonate" with the knowledge that it may not be acceptable to some of the more scientific minds in the audience -- and for whole systems, use of the existing high explosive inhabited building quantity-distance tables extrapolated by the formula $70W^{1/3}$ appears to be the only method which we can use. Industry generally, and many representatives of the Military Departments, wish to use a high explosive equivalency much less than 100% and, in many instances, less than 50%.

There is doubt in the minds of many authorities as to the need for requiring the full factor of $70W^{1/3}$ for the solid propellants as compared with high explosives. That this is a legitimate professional doubt is not questioned. Coupled, however, with the doubts that exist on high explosive equivalency factors, this necessitates that the risk factor not be reduced if less than 100% equivalency is assessed. To do so would be like taking credit twice for barricading and could lead to serious underestimates of the available damage potential.

UNCLASSIFIED

The Board Staff concurs that for many of the solid propellant systems and compositions in use today, siting on an original basis of 100%, Class 10 could result in excessive land acquisition costs. Also, there is significant evidence that if a percentage high explosive yield factor is at all valid, and it appears possible that it may be, it will be usually of an order of magnitude less than 50%. It seems likely that items which would produce yield much above 50% would be detonable and a yield approaching 100% would be expected. As yet, however, these postulations depend very much on how and where measurements are made, and perhaps by whom.

In consonance with the foregoing, I would like to again emphasize some of the particular problems involved in trying to achieve agreement on the assessment of high explosive yield. Most high explosive yield measurements made to date have been made on individual propellants. In very few cases has there been a coordinated effort to calibrate the test set-up and evaluate the measurements of peak pressure and impulse so that we can feel confident of our ability to correlate the yield figures assessed by one operator for a given propellant with those which might be assessed by another operator for the same or a different propellant. It is most important that these differences be resolved. We must determine whether or not a "high explosive equivalency factor" is a valid measurement of the hazard presented.

Many different types of gages and evaluation techniques are used. Relatively little information has been submitted to the Board indicating the method of arrival at the high explosive yield figures recorded. One report on a specific motor was reviewed, at my request, by an eminent authority on blast measurements. I quote his opinion. "The most singular comment to be made is that the report itself contains no evaluation of the blast pressure information presented. True, the author(s) presents 'raw Bikini gage results' in tabular form and lists respective pressures and corresponding values for percentage TNT equivalents but he does not demonstrate how the gage results were evaluated nor how he has analyzed them to yield the conclusions given."

I personally made equivalency calculations from the data in this report and compared them with the theoretical peak overpressure chart for large charges. In doing this, I found that the high explosive equivalencies differed at different distances from the test and unless some very important correction factor not cited in the report was used, it would be quite reasonable to postulate a near 100% yield from this particular propellant rather than the lesser figures given in the report. The reported values ranged from 22% to 58%.

Another area of uncertainty which some few observers feel is significant and in which a very inadequate amount of work has been done is that of the effect of charge shape upon the peak overpressure

produced. The indications of some recent research are that the pressure profile around a long, narrow charge can be very much different from that obtained from a spherical or near-spherical blast source. Based upon some empirical data obtained from relatively small charges, observers have indicated a peak pressure difference of several orders of magnitude based solely upon the position of the gage with respect to the long axis of the charge.

Last year at the seminar, I mentioned the Air Force MB-1 on which we have some 38 or s0 separate experiences which indicate a range of yield from the propellant of from zero to 100%. Special tests were arranged in an effort to resolve this difficulty. The weapons were detonated in the open air and peak pressure measurements appeared to indicate a yield of not more than 15% of the propellant weight for a detonation of the complete weapons. A full-scale exact configuration test of the MB-1 in a proposed steel igloo complex of Air Force design has since been performed under the auspices of the Armed Services Explosives Safety Board. Three weapons were detonated in the donor arch of a typical triple-arch test setup with one acceptor igloo at $1.25W^{1/3}$ and the other at $1.5W^{1/3}$. As you know, the proportion of high explosive warhead to propellant is about one to three in this weapon and the separation of the acceptor igloos was based on the combined weight of high explosive and propellant. The results of this test in their original gross form showed that the close-in damage done to the acceptor igloos was somewhat comparable to other tests in which a comparable charge of 100% high explosives had been used. Also, pressure measurements taken at a distance where the expected peak overpressure was on the order of one pound-per-square-inch "showed relatively little" high explosive yield from the propellant.

One purpose of my foregoing statements is to point out that in tests involving a computation of high explosive yield or for any other assessment of distant damage criteria from solid propellants, the measurements of peak pressure and impulse should be taken at sufficiently numerous positions in both azimuth and distance that they may be reasonably extrapolated to the entire range of interest. It appears that there is a significant likelihood that a high explosive yield factor for close-in damage criteria such as cratering and the destruction of protective inclosures and magazines would have to be different from the comparable factor which would be used for far-out assessment of damage, i.e., inhabited buildings.

One final word -- I would like to make a plea to all of the listeners here to be mindful of these problems in the carrying out of related test programs and to make every reasonable effort to acquire all of the data practicable from the tests for maximum

benefit to all concerned. Since the last Seminar, the Board has recommended an extensive program of testing to evaluate these unknowns. We are currently holding approximately thirty Polaris second-stage surplus motors at NAD Hawthorne, Nevada, to be used in any such program of full-scale tests which can be established and funded to further the state of our knowledge in this regard.

We of the Board Staff concur most heartily that full-scale, exact-configuration tests of large weapon systems are not economically feasible, and that a coordinated program of scale model, with very limited full-scale, tests must be established to solve these problems. The acquisition of the needed basic data must be started soon and must proceed apace. Until this is done, serious questions will continue to arise with regard to the safety of specific systems. We earnestly enjoin your cooperation, your wholehearted cooperation, in any efforts to establish such a program.

An extensive program embodying such tests as this is currently recommended for funding by the U. S. Air Force. All of you here should be alert to assist this program to get the maximum benefit from the contemplated expenditures.

Mr. McClellan: You mentioned MB-1 propellant, what is the classification of MB-1 propellant?

Mr. Perkins: The propellant in an unconfined condition would be considered Class 2. It is a composite propellant.

Mr. McClellan: Is this the class of the propellant which you mentioned in the two comparison tests as TNT?

Mr. Perkins: Yes, we used them in the tests that I am speaking of - actually MB-1s - these tests were performed for various purposes, impact sensitivity, high explosive yield, propagation separation between igloos and they gave all sorts of varied results. But the last test in this sequence that I described was the one with the three weapons in the igloo that was performed for verification of the side-to-side separation distance for the igloo. We made these pressure measurements for purposes of getting some additional data.

FRAGMENTATION STUDY ON LARGE SOLID ROCKET MOTORS

by

L. C. Walther - Aerojet-General Corporation
Sacramento, California

Recognizing the need to develop uniform fragmentation standards compatible with current systems, the Armed Services Explosive Safety Board (ASESB) established a work group to study the potential fragmentation hazards from large missiles and/or weapons systems.

Subsequently, a subcommittee was appointed by the ASESB to assist the work group in the study of this problem. Its function was to gather and review available literature and data pertinent to the subject; and ultimately to submit recommendations to the ASESB work group relative to the establishments of interim standards.

This sub committee was chaired by the Aerojet-General Corporation and was sponsored by AFSC, Andrews Air Force Base. Participants were ASESB members and industry consultants.

Existing fragmentation standards are felt to be inadequate and are aimed primarily at providing reasonable protection to life and property from the blast hazard characteristics of mass-detonating ammunition and explosives. The risks relative to fragmentation hazards from large weapon systems have not been defined and undue penalties may be imposed by the use of present quantity-distance QD requirements. Acceptable risk levels must be defined and what constitutes a hazardous fragment must be determined.

To assist the sub committee in this study, the U.S. Navy Special Projects Office made available four rejected second-stage Polaris Model A-3 Motors that had been scheduled for disposal. Engineered tests were performed on these motors and it is generally agreed that the results were a significant contribution to the fragmentation study program.

Many of you may recall that details relative to this program were discussed at the last ASESB Seminar.

The tests were conducted at the Aerojet-General Corporation Test Facility, Hawthorne, Nevada.

The test plan was designed to provide information on the fragmentation dispersal that is associated with a severe explosion of rocket motors that contain a Class 2 solid propellant. The tests were exploratory and have no direct application to the explosive classification or behavior of any particular missile or missile system. The objective of the program was to obtain quantitative data on the size of inert and propellant fragments and their projected distance from explosively destroyed motors.

Personnel support was supplied by various companies and governmental agencies that have an active interest in the subject. Because of this support, disposal data were collected rapidly and effectively and the program was conducted at a minimum cost to the government. Thirty-seven persons attended representing 18 organizations of manufacturers in the solid propellant industry. In fact these participants were really put to work and constituted what would have been a pretty expensive payroll.

Excellant support and cooperation was also provided by local Hawthorne, Nevada officials.

Unfortunately insufficient time is available to adequately discuss the resultant data, however a report has been prepared, AGC No. 0179-64F, which discusses in detail all aspects of the program. This report will be disseminated shortly throughout the industry. It contains all of the curves, formulas, density patterns, and fragment contours derived from the data.

The data indicate that it is possible to predict the range concentration, and weight of fragments from solid propellant motors. Additional tests have been recommended and we hope will be performed this year to provide back-up data and clarify questionable matters pertinent to the following areas:

1. TNT Equivalency,
2. Donar Charge Relationship,
3. Secondary Fragmentation, and
4. Relationship of Propellant Type and Classification.

I would like to emphasize the following:

Fragmentation standards must be developed as a separate hazard classification aside from fire and overpressurization. The potential fragmentation hazard from a solid motor, liquid motor, a warhead should be analyzed and siting based upon the maximum existing hazard for the particular operation or envelope. Of course the ultimate required QD will depend upon the maximum hazard that exists from the potential contribution from fire, overpressurization, or fragmentation for a particular propellant classification or envelope.

Before meaningful standards relative to fragmentation hazards can be developed, the following must be established:

1. Acceptable risk levels, such as frag concentration. Data from this program can be used as a guide but the determination of levels is felt to be the responsibility of a government group.

2. Maximum energy or physical condition to constitute a fragment as detrimental.

Data from this program is recommended for use in developing interim standards. The implementation of recommended tests to expend this analysis could very well significantly contribute to the ultimate establishment of fragmentation standards for solid propellant motors.

The Sound Color Documentary film you are about to see is self explanatory and covers highlights of the tests performed. This film will be made available to those desiring to show it to their plant or organization.

Mr. Walsh: What is the equivalent explosives that you used in relation to TNT or something similar to this?

Mr. Walther: We used on the first motor which contained approximately 10,000 pounds of propellant, 100 pounds of Airex internally for initiation. On the second test where we primed the two motors and the third motor which was adjacent did not have a charge, we used approximately 50 pounds each.

Mr. Walsh: What is this equivalent to?

Mr. Walther: It's equivalent to TNT, only slightly over TNT, slightly better than one.

Mr. Monteleone: I was just wondering if all your tests were run on the ground because of the coefficient of reflection. If they were in the air you would get a different blast pattern. This sort of makes me fear that this type of test gives you one blast pattern and an air blast would give you an entirely different blast pattern. Another point, putting the explosives inside on the grain gives you maximum contribution and will produce a monstrous amount of fragments. This would be pretty difficult to duplicate in a motor.

Mr. Walther: We've taken a lot of our data and we've analyzed it with tests performed on Minuteman motors and other motors at Edwards AFB. We've looked at some of the data which we've been able to obtain from Lou Ullian, we've analyzed some of the data from PMR and from other particular tests and we feel that the curves and the formulas that we have been able to develop with respect to maximum fragmentation distances and density patterns are fairly representative of what we could expect as far as applying this to a maximum hazard risk. The density factor of course of how many fragments per unit area is something that we feel that the military or a Government agency is going to have to decide. We do recommend

as far as future programs are concerned that in order to answer some of these gray areas that we do perform some air tests as well as ground tests. We have talked about silo tests, tests with hardware adjacent to it to get more secondary fragment information. We've even talked about using some launch tubes to get this type of interaction and fragmentation data. We hope to expand this and analyze what we have and wind up with something more constructive with relationship to TNT equivalencies and donor size and the information will be far more useful and at another presentation these questions we can basically answer.

Mr. Rindner: Did you correlate your data with any existing data on fragment distribution, particularly...ground distribution and second question, did you make any measurements of fragment patterns, especially the velocities that propelled the fragments as a function of the distance?

Mr. Walther: Yes, we did compare density patterns with existing test data as I indicated which has been performed at Edwards and other places which were some unplanned tests and tried to get correlation as closely as possible. We do find very close correlations and as far as the velocities are concerned, yes, we did plot these and they are shown in this report which is being distributed. The terminal velocities appeared to be in the neighborhood of 350 to 500 ft. per sec.

Mr. Jezek: Why were the motors put in a horizontal position when normally they would be in a vertical position is one question. The other, were both ends of a motor open when you put this explosive inside and was any thought given to suspending the motors on platforms or from some sort of tripod?

Mr. Walther: Both ends were open, the charge was in the igniter end of course. We did give consideration to the suggestions but could not effect them due to limited funding and the fact that these were defective motors. In some cases the one motor which had a crack had to be supported by the cradle. We had limited funding, the whole program was conducted for a minimum fee and a lot of it was done on overhead and as you know people donated their time to help get the data. We did what we could with the funds that were available but we would like to expand on these other areas.

Mr. Ullian: I'm a little surprised at Frank's question back there about the statement that you are overpriming the system. If you take a look at the results that you got from these tests and the results of the first stage Minuteman, you'll find if anything that the Minuteman results are more severe and there were no explosives as such on the Minuteman first stage....At least from AMR's standpoint

I think it was a good job and that these data report the results from actual missile failures that have been observed at AMR. I don't know how you can dispute data.

Mr. Walther: We appreciate the contributions from Lou Ullian and the people from Patrick AFB. They sent people all the way to Hawthorne with equipment and donated instrumentation. Also the people at NOTS China Lake donated instrumentation. And maybe in the future with a little more money and a little more coverage we can iron out some of the gray areas.

IMPROVED SAFETY THROUGH THE USE OF EXPLODING BRIDGEWIRE ORDNANCE DEVICES

By

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INTRODUCTION

During recent years, electroexplosive devices (EED's) have been utilized extensively on aerospace vehicles to perform a variety of complex functions. A few of these functions are: ignition, stroking, pressurization, stage separation, and destruct. The EED's discussed in this paper can be categorized as squibs and detonators.

DEFINITIONS AND BACKGROUND

Squibs function by deflagration of a pyrotechnic or propellant charge (low explosives) and are used primarily to initiate gas generators, ignition systems, and other propellant-actuated devices such as thrusters and ejectors.

Detonators function by detonation of a high explosive which primes or initiates other explosives or detonating cords in destruct systems and release mechanisms.

Two methods of electrical initiation are discussed: the "conventional" type, in which a heated bridgewire ignites a pyrotechnic or explosive composition; and the EBW type, in which actuation depends on rapid vaporization of the bridgewire.

Before 1959, "conventional" EED's were used exclusively. Each design had its characteristic combination of responses to various stimuli, but each was susceptible to activation by some level of the stimuli that occur unpredictably in their environment of storage or use. The catastrophic consequences of such premature ignition or destruction of a rocket spurred the design of a device known as a safe-arm unit. Such a mechanism imposes a mechanical block in an ignition or explosive train until an "arm" command signal is applied to remove it. These devices compound space, weight and reliability problems. When the exploding bridgewire phenomenon was employed for use in EED's, the trend reversed toward building inherent safety into the EED's themselves, thus obviating the need for a safe-arm mechanism.

DESCRIPTIONS

The external appearance of a conventional and an exploding bridgewire ordnance device can be the same. Internally, they are different as Figure 1 illustrates. Shown here are two "pigtail leadwire" squibs. The conventional squib on the left has a thermally sensitive bead on the bridgewire, and two other relatively sensitive charges surround the bead. These charges are sensitive also to heat, friction, impact, and electrostatic charges. The "sensitivity" of such devices depends primarily on the size and type of the bridgewire and the nature of the mixture surrounding the wire. Requirements for rapid functioning at low current levels, however, have necessitated the frequent use of sensitive explosives in combination with bridgewires of high resistance. Thus, the mechanism of transforming a weak electric pulse into energy capable of initiating pyrotechnics and explosives provokes a struggle to maintain or improve safety and still meet operational requirements. When slightly over 1 ampere of current flows through the bridgewire of this conventional squib, developing around 300°F, the squib will ignite. The bridgewire does not have to melt to propagate ignition. The firing current for this squib usually comes from a battery when functioning is desired, but it may also be developed inadvertently from stray electromagnetic or electrostatic energy.

The exploding bridgewire squib, on the right, does not have a sensitive bead on the bridgewire nor a sensitive charge surrounding it. The main difference is in the explosive compositions. The response of the charge surrounding the bridgewire is dependent on the rate at which energy is released; that is, the charge will not ignite if the bridgewire is heated to incandescence or to the fusion temperature of the wire. It will ignite, however, when the wire is explosively vaporized by a short-duration, high-current pulse from a capacitor charged to a high voltage.

Conventional detonators and squibs contain primary explosives, such as lead azide, lead styphnate, and mercury fulminate, as the initiating portion of an explosive train. In an exploding bridgewire detonator only secondary high explosives are needed. For instance, a properly sized exploding bridgewire is capable of initiating PETN directly; thus the device is extremely simple, requiring only one explosive charge. Of more importance is the fact that avoiding the use of primary explosives improves the safety of the device.

The current necessary to achieve bridgewire explosion, which is produced by sudden release of electrical energy in a metal wire, must have a short rise time. In practice, a 1.0 microfarad capacitor charged to a nominal 2000 volts is rapidly discharged into the squib bridgewire through a

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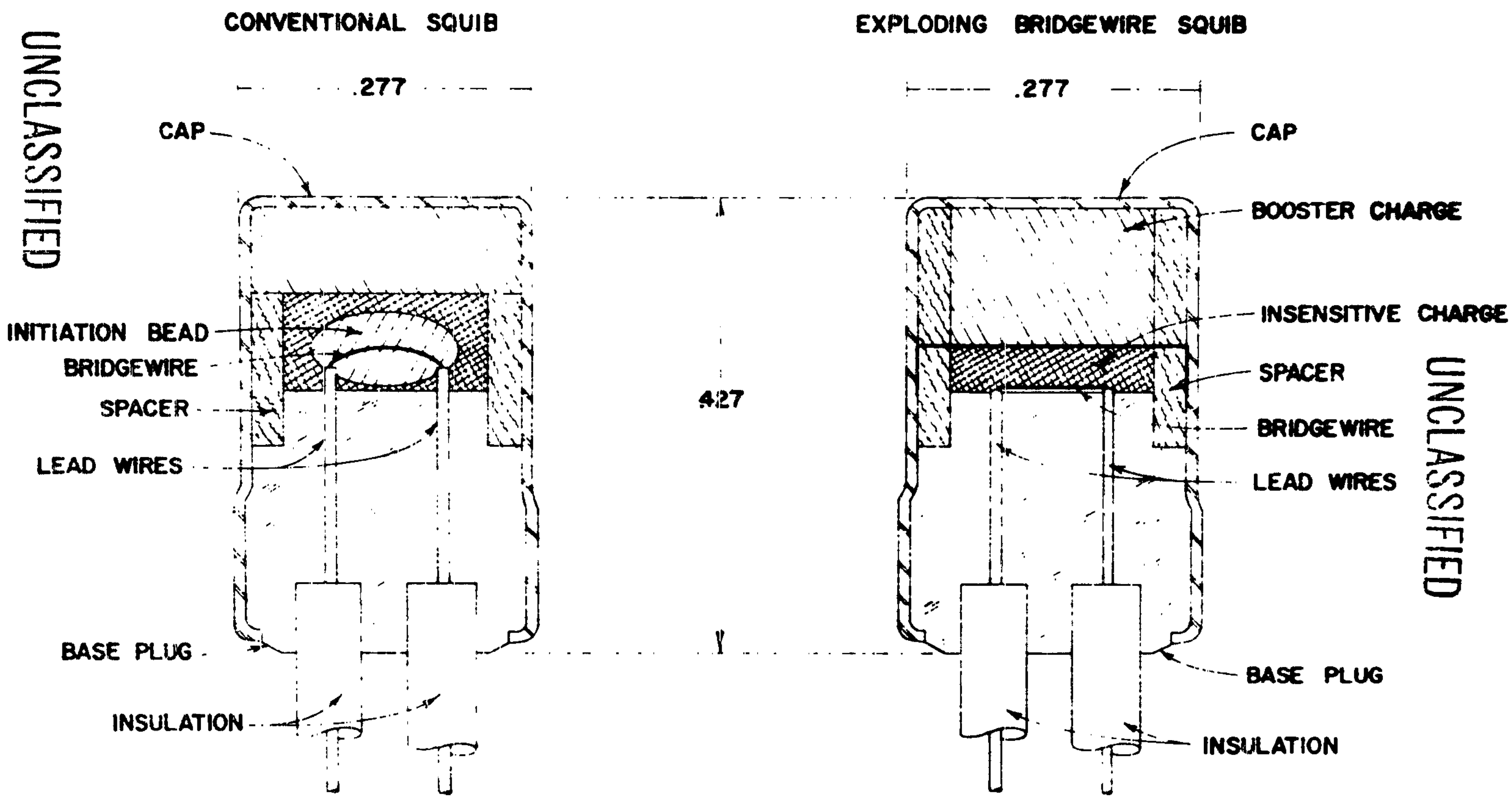

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Figure 1. Cross Sections of Conventional and Exploding Bridgewire Squibs

circuit of low impedance and inductance. Figure 2 illustrates a typical EBW firing circuit. In less than one microsecond, a peak current on the order of 1000 amperes is reached (depending on bridgewire resistance, transmission line length and other factors) at the bridgewire, causing it to vaporize with explosive violence. The resultant energy release over a short time interval of a few microseconds, causes the development of a pressure wave and the achievement of a very high temperature, which ignites the insensitive chemical mixture surrounding the bridgewire.

EXPLODING BRIDGEWIRE SYSTEM DESIGN CONCEPTS

The following general approach has been used successfully in system design.

1. Development of pyrotechnic or explosive compositions that are compatible with the EBW concept. These compositions must not be susceptible to bridgewire heating, to electrostatic discharges, to self-heating from exposure to r.f. energy, or to impact. Good storage stability and adequate ordnance output are prerequisites. These characteristics eliminate the need for various gadgets in the bridgewire circuit to block a.c. or d.c. voltages from the bridgewire below a certain breakdown level. Spark gaps, diodes and other devices should not be utilized to hide the fact that conventional squib technology is being used. R.f. and electrostatic charges <u>are not</u> blocked by these "gadgets" and the EED's using such may not be safer than conventional items. Basically, the items should be safe before voltage blocking devices are employed.

2. The above factors must be correlated with the firing unit output (voltage and capacitance) and discharge characteristics. Impedance and inductance of the transmission cable plus cable, power supply and EED interfaces are important considerations.

3. To demonstrate high reliability in the field, laboratory tests should show that the desired reliability or functioning probability is achieved with only 50% of the expected firing energy.

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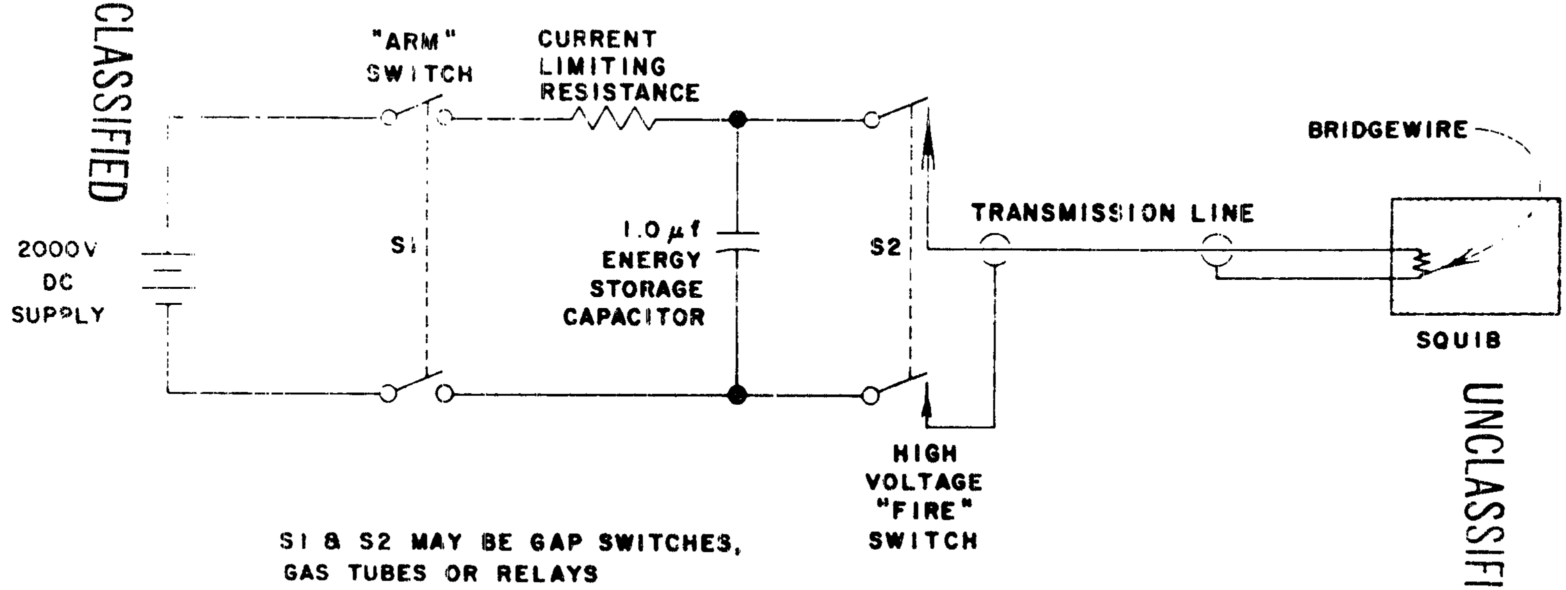

Figure 2. Basic E. B. W. Firing Circuit

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SAFETY

Safety requirements controlling the use and application of these devices have become more stringent with the advent of manned space flight and the development of enormous rockets with the potential for widespread destruction of life and property.

The ever-present, high-powered radar on ships and around launch sites poses a real hazard to EED's. Much effort is being expended towards "safing" EED's from electromagnetic radiation. The HERO Congress sponsored by the Department of the Navy is particularly active in this area[1] The use of alternating current on space vehicles during prelaunch check-out and for ground support equipment at launch sites is common practice. And of course, the insidious electrostatic charge, accumulated by whirling helicopter blades, flowing fluid, and personnel, is still the most common "stray" energy source. These hazards are in addition to impact, moisture, vibration, temperature extremes, and changing pressures which threaten the integrity of the EED's. Let us examine in detail some of these safety hazards.

Electrostatic Charge Safety

Although the safety of a conventional squib from accidental ignition by current flow through the bridgewire could be increased by a further increase in the bridgewire diameter, the current needed to fire the squib rapidly would be high and require a large power supply. Also, since Ohm's law applies, the unit becomes susceptible to low-voltage initiation. Furthermore, changing the bridgewire would not improve the electrostatic resistance of this squib, since electrostatic charge safety is not dependent on bridgewire size. A spark discharge could readily occur inside the squib between the bridgewire terminals and the metal case. Figure 3 illustrates several mechanisms by which a squib can be ignited by electrostatic charges. Diagram A of Figure 3 indicates that the squib may be fired when the charge on an energy storage device (such as a person, a truck body, a cable, an airframe, etc.) is discharged between the squib case and the shunted leadwires. In such a situation, only a few thousand volts will cause a spark to occur inside of the squib and ignite the charge. (For reference purposes, the human body can readily accumulate a static potential of 10,000 volts, and a helicopter in motion can build-up potentials from 25,000 to 60,000 volts.) The static discharge need not occur directly between the case and leadwires to ignite the charge, since as illustrated by Diagram B, if one plate of the squib (such as the shorted leadwires) is grounded or connected to an energy storage device that is discharging to ground, the other plate (such as the case) would assume the opposite polarity by induction, and a spark could occur inside of the squib.

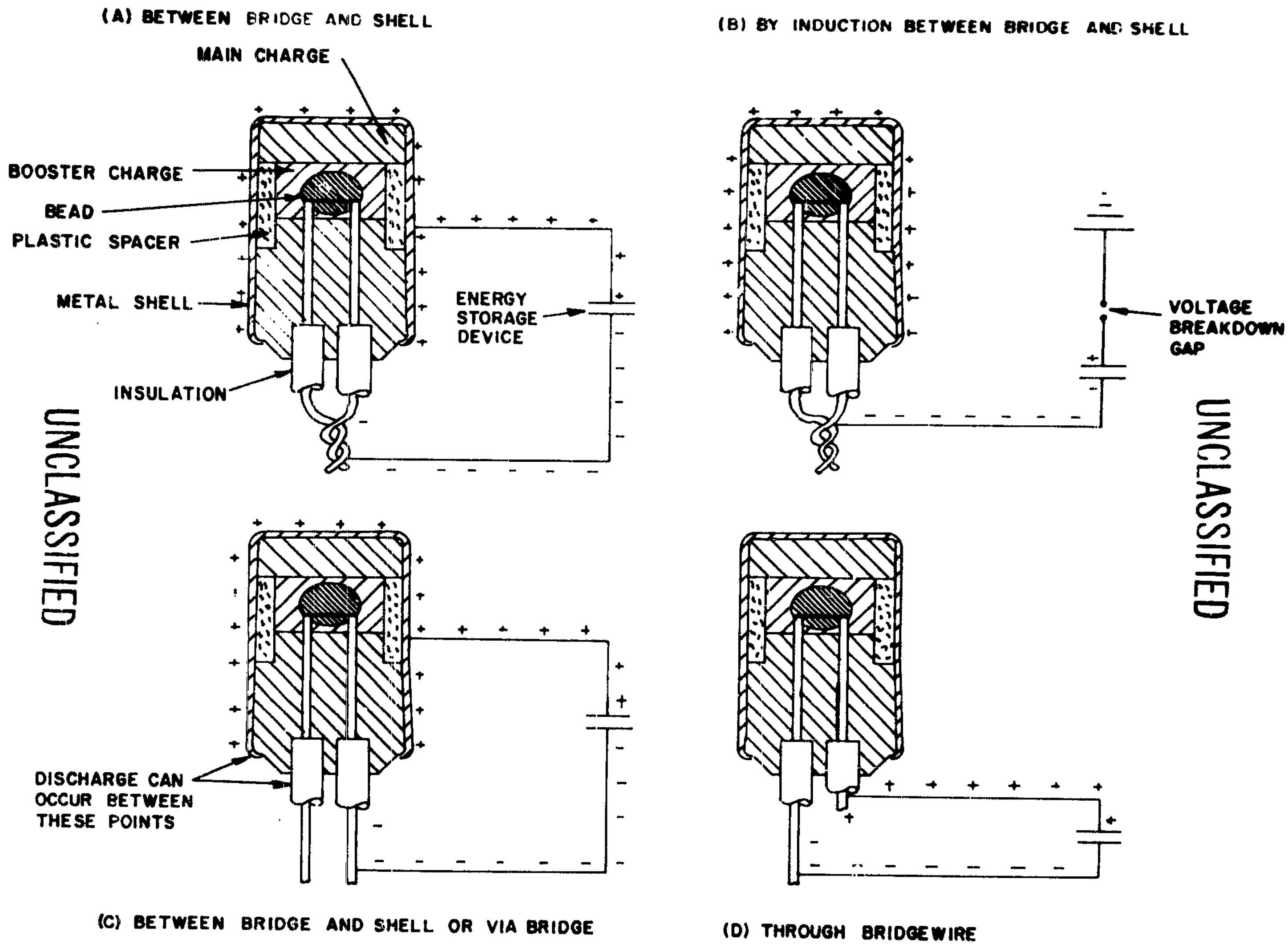

Figure 3. Methods by Which Electrostatic Discharge Can Cause Squib Ignition

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For static charge ignition by induction, a slightly higher voltage is necessary than for the direct method (Diagram A).

Diagram C illustrates a static discharge mechanism in which the discharge may occur from one wire to the case while sparking through the explosive, or through the bridgewire after breaking down the insulation on the adjacent leadwire. Diagram D represents the safest configuration for squibs (with continuous bridgewires), from the standpoint of electrostatic discharge, because a large amount of energy can be dissipated by the bridgewire. However, this configuration would be the most hazardous condition if the bridgewire were broken, since a very low energy spark across the broken wire would ignite the sensitive bead of the squib.

Electromagnetic Hazards

All transmitters of radio frequency energy, such as radar, create a field of electromagnetic energy surrounding their antennas. If the configuration of the squib leadwires is favorable and the transmitter is close enough and powerful enough, the leadwires may pick up sufficient current to heat the bridgewire and ignite the squib. Objects around a squib or an igniter can act as reflectors and amplify the energy pickup[2].

Since the radio frequency problem is extremely complex from the standpoint of comparing the power received by a squib to that required for initiation, a simple assessment as to the degree of radio frequency hazard that exists for a squib is not possible. However, it has been established, in tests conducted on some of the safer conventional squibs, that they will fire, with their leads in dipole configuration, at a field density of 3.5 to 10 milliwatts/cm^2.

Exploding bridgewire squibs of the pigtail lead type have survived fields in excess of 20 milliwatts/cm^2. These units may become duds, but do not ignite until the inert components of the squib begin to burn.

EED's utilizing the threaded metal shell and glass insulator with integral connector are still safer to r.f. than the leadwire type. The use of glass instead of plastic removes the combustible material that may ignite by dielectric heating and the shell acts as a shield. Examples of some metal shell designs are shown on Figure 4.

The Army Missile Command has subjected the XM6 squib, shown at the top right on this figure, to r.f. tests[3]. Figure 5 shows a cross-section of this squib. The squib was connected across the terminals of a receiving

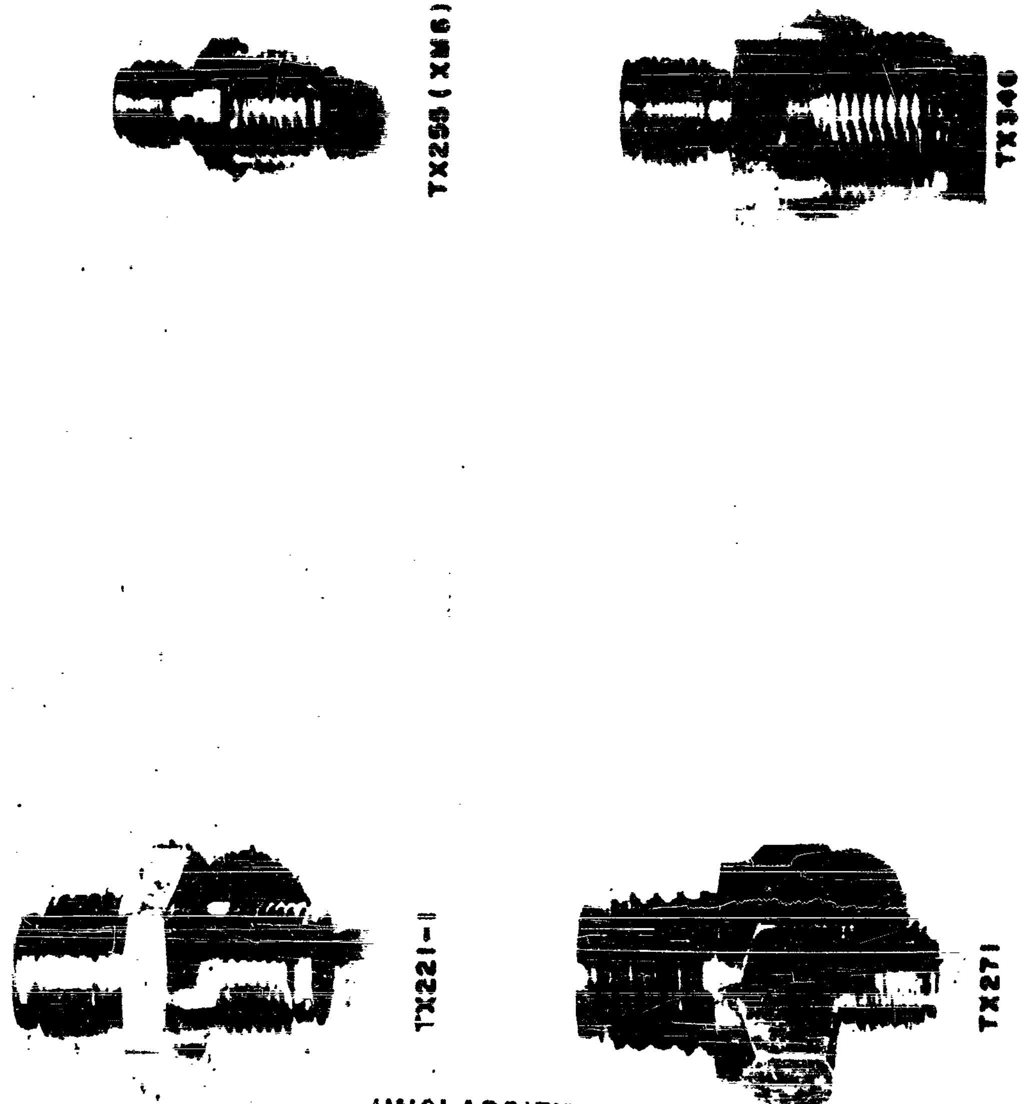

Figure 4. Threaded Metal Shell E. B. W. Squib Designs

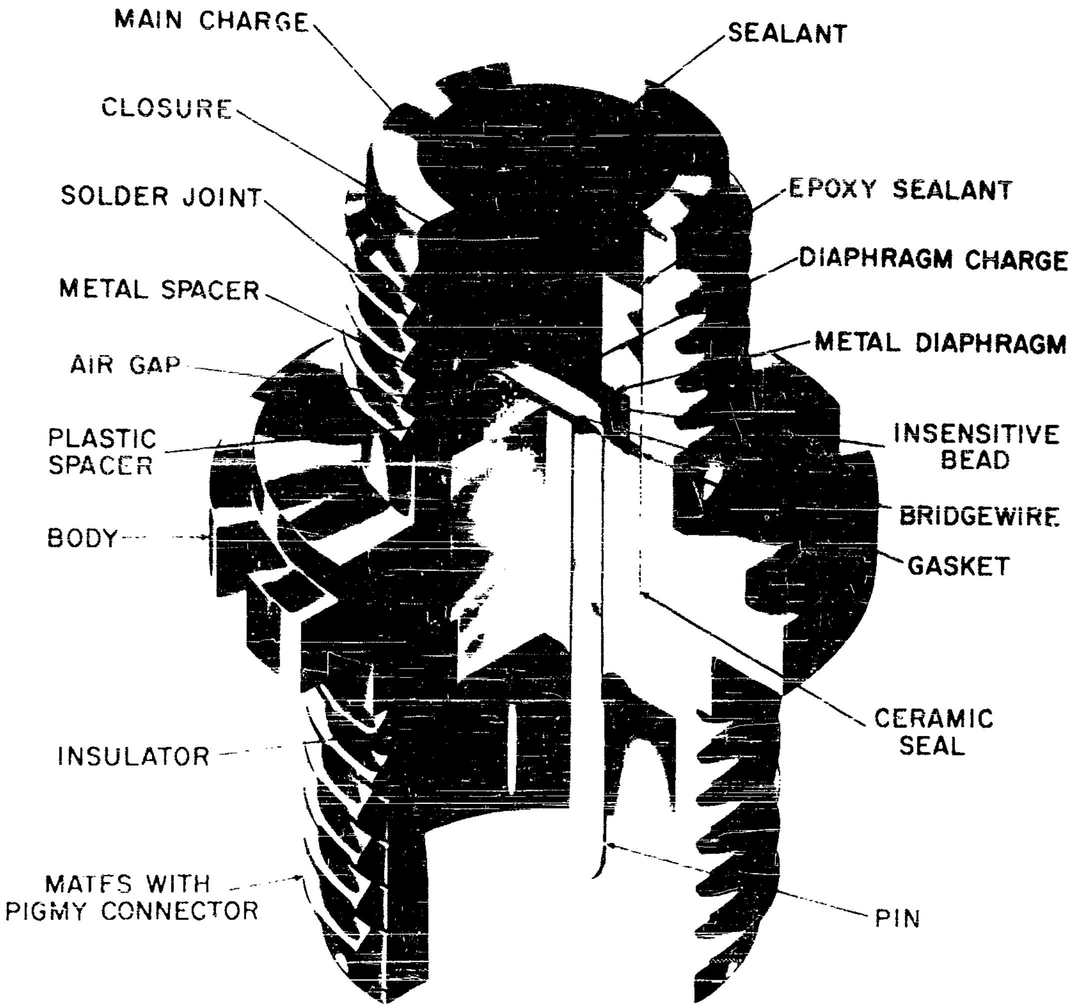

Figure 5. Cross Section of TX2[illegible] (XM6) Squib

	CONVENTIONAL SQUIB	EXPLODING BRIDGEWIRE SQUIB
NO FIRE CURRENT (MAX.)	1.0 AMP	>200 AMP
NO FIRE VOLTAGE (MAX.)	0.25 VOLTS	>50 VOLTS
NO FIRE STATIC CHARGE ENERGY (MAX.) (CASE TO LEADS)	2.2 m.j.	>225 m.j.
NO FIRE STATIC CHARGE VOLTAGE (MAX.) (CASE TO LEADS)	3000 VOLTS	>30,000 VOLTS
NO FIRE TEMPERATURE (MAX.)	275 °F	>600 °F

Figure 6. Comparison of Typical Squib Electrical Safety Characteristics

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NO FIRE SAFETY CHARACTERISTICS	TX346 SATURN ULLAGE SQUIB	TX255 (XM6) NIKE HERCULES RETROFIT SQUIB	TX221 PERSHING SQUIB	TX271 (XM70) NIKE HERCULES RETROFIT SQUIB	TX241 FALCON SQUIB	TX274 PERSHING THRUST CONTROL EXPLOSIVE SECTOR	TX273 PERSHING DETONATOR
VOLTS, 1 MFD CAP	500 (MIN)	500 (MIN)	500 (MIN)	500 (MIN)	500 (MIN)	500 (MIN)	500 MIN
VOLTS, DC, (0.1 OHM SOURCE)	GAP BREAK-DOWN (600 VOLTS)	72	60	72	60	36	36
VOLTS, 0.0005 MFD CAP.	5KV (MIN)	30KV (MIN)	30KV (MIN)	30KV (MIN)	25KV (MIN)	25KV (MIN)	25KV (MIN)
AC, 400 ~	250 (MIN)	NOT REQ'D	NOT REQ'D	NOT REQ'D	NOT REQ'D	NOT REQ'D	NOT REQ'D
LOW CURRENT, DC, TO BRIDGE *	BLOCKED BY SPARK GAP	1.75 AMP	2.5 AMP	1.75 AMP	1.75 AMP	1.75 AMP	1.75 AMP
TEMP, °F	600 FOR 8 HRS	675 FOR 8 HRS	650 FOR 8 HRS	675 FOR 8 HRS	850 FOR 15 MIN	320 FOR 20 MINS	320 FOR 20 MINS
STATUS	UNDERGOING QUALIFICATION	QUALIFIED	FLIGHT QUALIFIED	QUALIFIED	PFRT	FLIGHT QUALIFIED	FLIGHT QUALIFIED

* SAFE AT HIGHER CURRENT LEVELS, BUT BRIDGEWIRE MELTS AND OPENS CIRCUIT.

Figure 7. Safety Characteristics of E.B.W. Ordnance Devices

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antenna. The r.f. transmitter was loaded into the receiving antenna and then operated at 143 m.c. The output at this frequency was approximately 700 watts. At no distance from the transmitter could the squib be fired or dudded when tested in this manner.

EBW VERSUS CONVENTIONAL SQUIBS

A comparison of several pertinent safety characteristics of a conventional squib versus an EBW squib are shown in Figure 6. Conservative values for the EBW squib are used because ne of its safety characteristics are beyond the range of the equipment normally used to assess these features. However, in terms of current and voltage, the EBW squib is safer than the conventional squib by a factor of at least 200; in terms of electrostatic energy, the EBW is safer by a factor of over 100; in terms of electrostatic voltage, the EBW is safer by a factor of at least 10; and in terms of autoignition temperature, the EBW is safer by a margin of 300°F.

Figure 7 shows a tabulation of the safety characteristics and the status of several Thiokol EBW devices[4,5]. The flight-qualified TX221 ignition squib and TX274 explosive sector for the Pershing missile have an outstanding safety and reliability record. There have been no instances of accidental initiation. These devices have been used without a failure on 164 full-scale motor static tests and 58 missile flights. This is a total of 280 full scale motors. In addition, hundreds of development and sub-system tests have been performed.

The functioning reliability of such devices is in excess of 99.9% at 95% confidence.

SUMMARY

Present day EBW technology is providing reliable EED's safe to stray energy sources, human error, and equipment failure. These devices are now flying on Pershing, Saturn, and Polaris. There have been no known instances of accidental initiation. It is still conceivable that accidental activation could be caused by exposure to high temperature or by a near-by lightning strike; but the EBW system provides a closer approach to complete safety than any other existing system.

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Mr. Tweed: You mentioned that these items could be dudded by RF, but that specifically the XM6 was not dudded at 143 mc. Is that correct?

Mr. Graves: That's correct.

Mr. Tweed: Can you tell me at what frequency it can be dudded?

Mr. Graves: This was not determined so far as I could tell from the report. They just gave the specific frequencies, they varied the distance from the transmitter to the unit and we don't have the frequency at which it was dudded.

Mr. Tweed: It might be of interest to note that another item of a similar design was dudded at 3,000 m.c. at 4 watts of RF power, so you might look into that.

Mr. Graves: This wattage was calculated based on the frequency of 700 watts and they could not dud it or fire it.

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QUANTITY-DISTANCE CRITERIA FOR LIQUID PROPELLANTS

by
R. C. Herman
Armed Services Explosives Safety Board

In our opening session Col. McCants briefly discussed the ASESB and some of the work in which we are presently involved. I would like to tell you a little more regarding two of our work groups. The first of these is the Work Group to Develop Quantity-Distance Criteria for Bulk Storage of Liquid Propellants.

Ever since the end of World War II when we started firing some German V-2 rockets, we have been faced with the problem of safety in the storage of bulk liquid propellants. In 1949 the Navy Department attempted to develop storage criteria for liquid propellants and published what is commonly called the "Navy Gray Book." This was the first attempt on the part of any Service to prescribe safe distances for storage facilities of liquid propellants. The ASESB foresaw the necessity for such distances and requested that the Navy Department furnish copies to the Army and Air Force for consideration.

The Board suggested to the Services in 1949 that they correlate actual field experience with this book in order to produce the best available criteria. After a period of time the "Gray Book" was to be revised and uniform criteria published by the three Military Services.

Between 1949 and 1959, various attempts were made by different agencies to revise this document; however, due to insufficient data to accomplish the task, each attempt was dropped. Along about 1959 there was renewed interest in developing uniform storage criteria for these propellants. The agencies then responsible requested the various companies which manufacture liquid propellants to furnish any information which might assist in the development of storage distances. With few exceptions, the response to these inquiries furnished little or no information which could be used in developing storage criteria for the military. I would like to add, however, that this is no reflection on industry. The problem with which we are faced is much different than that in industry. The military must deal with many propellants in large quantities at one location for considerable periods of time; whereas industry may be concerned with a single propellant in limited quantities for a short time. We have to consider the possibility of accidents due to personnel who are not as highly trained in the handling of all propellants as the employees in industry are trained in the handling of a single propellant.

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Since the response from industry was of little value in solving the military problem, a letter from the Office, Secretary of Defense was sent to the Chairman of the ASESB on 27 September 1961 instructing the Board to take on this problem and develop uniform storage criteria for liquid propellants.

The Board formed a work group to develop the required criteria. This work group is comprised of two members from each of the three Military Services and two members from NASA and is chaired by a member of the ASESB Staff.

The problem was first attacked by developing a list of propellants which were being used in quantity by the military or proposed for use in quantity in the near future.

An attempt was made to determine the explosive characteristics of each propellant in order to determine the associated hazards. Technically speaking, each propellant has its own characteristics and would require a specific set of criteria to meet these characteristics, however, insufficient data now exists on each propellant to develop individual tables. It was then decided to establish a series of general hazard characteristics and from this develop groupings for those exhibiting like or similar characteristics. In this manner, four groupings were established. These are generally as follows:

1. Fuels which are moderate fire hazards.

2. Oxidizers which exhibit the basic characteristic of supporting combustion, sometimes violently, within predictable limits.

3. Fuels which are severe fire hazards and may sustain vapor phase explosions.

4. Detonating propellants.

The next step was to develop distances for each group. These distances were to include tank-to-tank separations within a group, group-to-group separation and inhabited building separations for the groups and combinations. Published standards by the National Fire Protection Association and the petroleum industry were reviewed and personnel at the NASA Lewis Research Center and Naval Research Laboratory were consulted. Suggestions were made as to various scientific approaches to the problem but because of the lack of basic data, extensive research programs would be required to develop the required information. Even if funds were available for such research, many months would pass before any useful data could be developed. The

group therefor decided that reasonable criteria should be developed based on the best information available at the present time. Such criteria can be up-dated as new data becomes available.

In addition to the problems of fire, explosion and detonation, which is the basis for the above groupings, some fuels present toxic hazards. You probably have noted that there has been no mention of toxicity in these groups. Since this hazard is primarily a medical problem, it must be dealt with by the Surgeons General of the Services. In the proposed storage criteria prepared by the work group, those propellants which present a toxic hazard have been identified, with the precaution that medical advice should be obtained regarding them.

Once the basic part of the document had been completed (the separation distances mentioned above), other problems arise. The distances specified for the above separations are based on the general characteristics of each group. Of course if these various propellants are allowed to mix the hazards are significantly changed. It then became necessary to look at actual missile launch and test stand operations and to provide guidance as to when propellants will be treated as individual chemicals or combinations of two or more chemicals.

The Board has another work group which has been assigned the mission of developing uniform explosive equivalencies for mixtures of liquid propellants. I will not go into the many problems of this group or the pros and cons of explosive equivalencies of propellants. I will say, however, that this group has made recommendations as to the explosive equivalencies for certain mixtures of liquid propellants presently being used in missiles and space vehicles.

These explosives equivalency recommendations were taken and included in the document in order to furnish guidance whenever mixtures of propellants are encountered. This may occur when separation distances are not maintained between groups or at launch or test stands.

As previously stated, the efforts of this group were directed toward development of a uniform standard for separation of liquid propellant facilities based upon the best information presently available. It is the intent to revise and up-date this document as new information becomes available.

One method of acquiring additional information is thru test programs. One such test program has recently been instituted at Edwards Air Force Base which is jointly funded by NASA and the Air Force. This program is designed to develop basic data on the explosive phenomena of mixtures of liquid propellants. Such tests are to be essentially divorced from any specific missile configuration

and are designed to develop data such as effects of tank configuration, surface to volume ratio, modes of initiation and ignition delay effects. There are several size tests to determine scale-up effects. It is anticipated that the results of these tests will yield data useful in the design of missiles to reduce hazards and is of paramount interest to existing work groups charged with developing safety criteria. Of course it will be several months before any concrete data will be available from these tests.

I might mention another series of tests which are also being jointly funded by NASA and the Air Force and are being conducted at the Army Chemical Center, Edgewood, Maryland. These tests originally started out to determine firefighting methods for liquid propellant mixtures but are now concerned with fume suppression; evaporation rates of propellants when spilled on various surfaces and other data which will be a significant contribution to basic data required for safety purposes. Preliminary tests have been conducted in the spring and enlarged highly instrumented tests are presently being conducted. It is anticipated that first results of these tests will begin to come in before too long.

In the next presentation, you will hear of another proposed test program which will expand our knowledge of propellant behavior.

The results of all of these tests will have a direct bearing on the quantity-distance criteria for liquid propellants; however, due to the extended period of time before these results are available, it has been decided to proceed with the existing document and later modify it to bring it in line with the test results. We will at least have one uniform set of criteria used by the Military Services.

The second work group I would like to discuss briefly is the Work Group to Develop Minimum Test Criteria for Solid Propellants.

As many of you know, the minimum test criteria for solid propellants was published as Section III of the tri-Service document entitled "Explosives Hazard Classification Procedure" dated 31 July 1962. This document as published contained the best available information at that time. It is our intent to revise this document and keep it current with the latest information.

Since the publication of this document we have had many oral comments and suggestions regarding changes to it. As you are aware, such comments must be reduced to writing in order that they may be considered by the Work Group. I therefor ask you to please send your comments, suggested changes and any other substantial information to us in order that we may revise this document. Our desire, of course, is to furnish you with the best available information but you must assist us by furnishing data with which we may work.

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FILM

A PROPOSED PROGRAM FOR THE EVALUATION OF THE EXPLOSIVE HAZARDS OF THE TITAN III

by

Major H. J. Eberle, USAF
Space Systems Division
Air Force Systems Command
Los Angeles, California

Maj. Eberle: The thing I want to point out is all the programs we have forced into this year of milling around and trying to get some guidance. We hope that by having spent this year, we can aid any other program that has to go the same route. Unfortunately for us we got there first, but fortunately I believe we are taking the right approach, everyone tells us we have. I would like now to have Mr. Hy Ackerman from Air Force Systems Command Headquarters tell us what has been developing at that level. When you get back to your office, if you have any comments on this report, please let us have your comments. Don't tell us of any misspelled words, don't tell us that the committee obviously wasn't aware of the reliability of the destruct systems. The committee only knew what we gave them and they assumed that if one missile impacted this way, ours would impact the same way. I don't know what other system we can expect them to work under. Give us comments though that will help the program.

Mr. Ackerman: We realized that for a long time the Air Force has had the conviction and the contention that to insure that the system project officers had information before the item has become a system, certain research and development and technological studies for safety requirements had to be accomplished way before the system was even conceived. Unfortunately the Titan III didn't have this information and at the present time they have experiences, the problems that any system developed within the Air Force or any other activity without insuring that the information is available on safety criteria causes the delay in trying to acquire the real estate, designing the facility. At the present time, and this has been going on for about two years, the Air Force has recognized these requirements and has started a

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program under the auspices of the USAF to insure that the research and development technology divisions of AFSC start a program to develop the hazard data for liquid propellants and ordnance materials to insure that when a system does become conceived, that they have a basis for their assumption and for their information. This does not preclude the fact that the systems people will have to continue to do some additional test work but it does give them an opportunity to know what they had and what they can do with these items. At the present time this program is up before USAF for approval action on funding and manpower. Of course this is always a problem. But we have great hope because at the present time the Air Staff is completely in favor of AFSC accomplishing this mission for the Air Force. We have General LeMay's office as well as General Ferguson and General Curtins' office completely in back of this program and we are extending at the present time - Mr. Maguire has the program at Rocket Propulsion Labs to integrate the requirements of this particular study in the existing testing and evaluation program. We hope that within two years that we will be able to answer questions to any other SPO that is conceived for a system.

Maj. Eberle: The gist of this thing was that by directing all this attention in getting this document we're in a better position to get support from above, which has long been needed. Last year Dr. Zernow made a long loud pitch that five years ago he recommended this type of thing be done.

REPORT NO.
1939.32-AHC-1

A Proposed Program for the Evaluation of the Explosive Hazards of Titan III

1 JULY 1963

Prepared by

THE TITAN III EXPLOSIVE HAZARDS AD HOC COMMITTEE

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Report No.
1939. 32-AHC-1

A PROPOSED PROGRAM FOR THE EVALUATION OF THE EXPLOSIVE HAZARDS OF TITAN III

1 July 1963

Prepared by

THE TITAN III (624A) EXPLOSIVE HAZARDS AD HOC COMMITTEE

Chairman: Dr. A. M. Ball, Hercules Powder Company

Committee Members

Dr. A. B. Amster, Stanford Research Institute

Dr. R. W. Van Dolah, Bureau of Mines

Dr. Donna Price, Naval Ordnance Laboratory

Dr. L. Zernow, Aerojet-General Corporation

J. R. Wood, Aerospace Corporation, Project Engineer

W. M. Smalley, Aerospace Corporation, Technical Adviser

Major H. J. Eberle, Space Systems Division, Project Officer

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HERCULES POWDER COMPANY
INCORPORATED
HERCULES TOWER · 910 MARKET STREET · WILMINGTON 99, DELAWARE

June 17, 1963

Mr. J. R. Wood
Aerospace Corporation
P. O. Box 95085
Los Angeles 45, California

Dear Mr. Wood:

624A AD HOC COMMITTEE ON EXPLOSIVE HAZARDS

The report of subject committee has been transmitted to you under separate cover, and the committee considers itself disbanded. It is our sincere hope that we have contributed something toward the solution of this problem.

In concluding its work, the committee wishes to recognize the many courtesies and complete cooperation shown by the individuals and facilities consulted, notably:

Dr. George Bryan	STL (AMR),
Mr. Gerald Couch	UTC,
Lt. Kenneth Duke, USN	PMR,
Mr. R. C. Herman	ASESB,
Mr. L. J. Ullian	AMR,

in addition to Maj. H. Eberle, USAF, Mr. W. Smalley and yourself. It has been a pleasure to work with you.

Yours very truly,

Adolph B. Amster
Donna Price
Robert W. Van Dolah
Louis Zernow
A. M. Ball, Chairman A M Ball

AMB:bas

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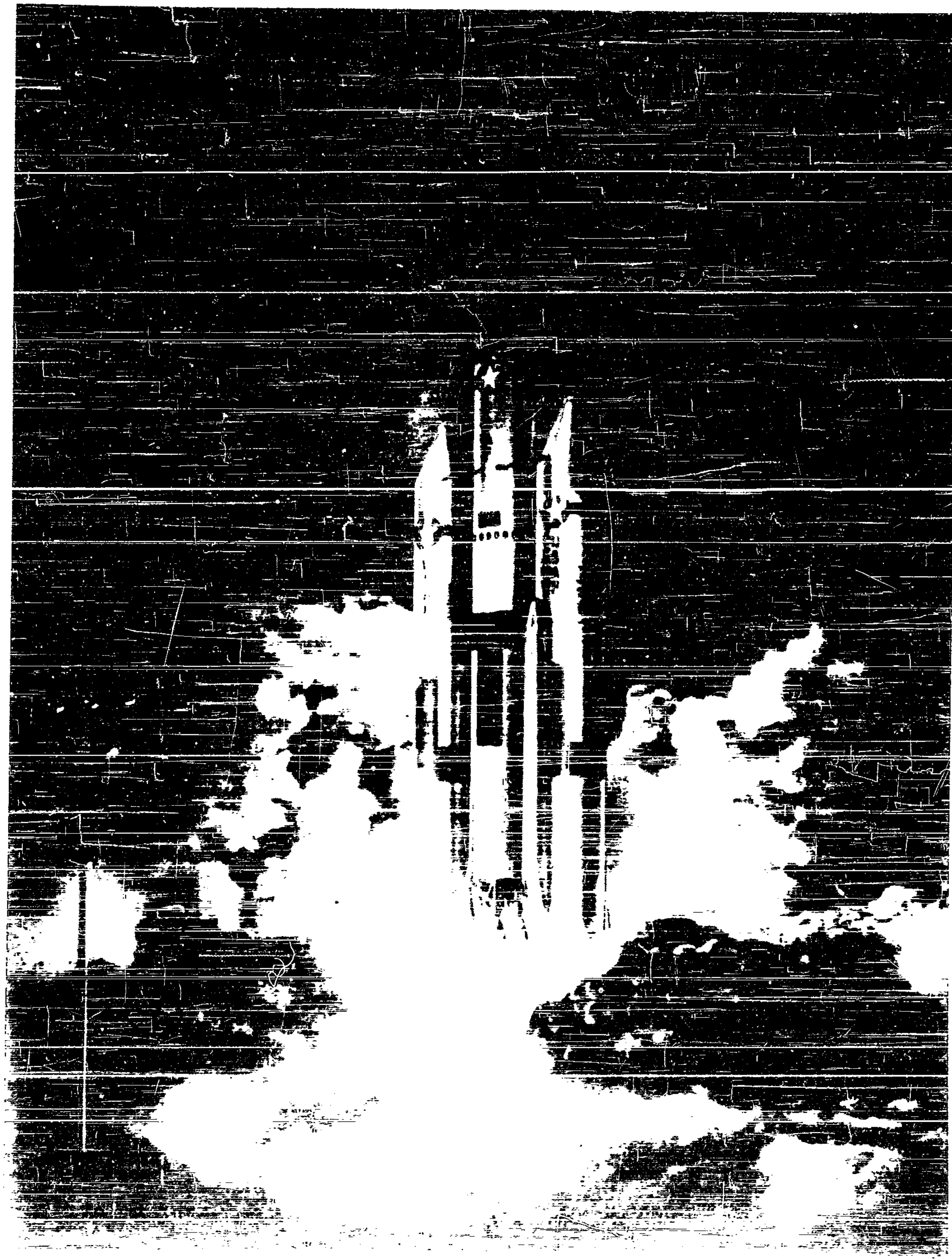

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A PROPOSED PROGRAM FOR THE EVALUATION OF THE EXPLOSIVE HAZARDS OF TITAN III

INTRODUCTION

The Titan III Standard Launch Vehicle (Program 624A) is designed as a standardized work-horse booster for launching various payloads into many different orbits. In order to vary the trajectories of different size payloads, a building block concept has been developed for the booster. As a result, two very large solid rocket motors have been added to a modified Titan II Intercontinental Ballistic Missile which contains hypergolic liquid propellants. This combination for the first time has brought together, in such large quantities, solid rocket motors with an unknown hazard potential, and a liquid fueled core of unknown hazard characteristics.

In addition to investigating the reaction of the solid motors when subjected to a known donor, it is necessary for range safety reasons to characterize the reaction of the solids when subjected to different possible environments produced by the liquid core.

In an effort to determine the hazard potential of the Titan III system, existing data and theories have been investigated. The Interstate Commerce Commission (ICC) has devised certain standard tests which determine the shipping classification as either Class A (mass detonating explosive) or Class B (fire hazard only). Similarly, the Armed Services Explosives Safety Board (ASESB) has issued an "Explosives Hazard Classification Procedure," U. S. Air Force

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Technical Order, TO 11A-1-47, dated 31 July 1962, which establishes uniform criteria for tests from which hazard classifications and hazard characteristics can be determined.

However, since TO 11A-1-47 prescribes tests on solid propellant motors up to only 8 inches in diameter, considerable concern has been expressed about the validity of extrapolating the results of such tests to the 120-inch segmented solids used in combination with the hypergolic liquid propellants in the Titan III vehicle system.

To resolve this problem, a meeting was conducted in March 1962, by Space Systems Division/Aerospace to devise an acceptable explosive hazard classification test program. Representatives of Atlantic Missile Range (AMR), Pacific Missile Range (PMR), and Edwards Air Force Base (EAFB), were present. No attempt was made at this meeting to determine the actual classification of the motors. The inability of the attendees to agree on an acceptable test program resulted in the following recommendations being made:

1. The Aerospace Corporation should obtain the services, as consultants, of five qualified experts in the explosives field. These consultants would be selected by SSD/Aerospace from those recommended by the attendees.

2. The consultants should meet as an ad hoc committee to devise an explosive classification test plan for Titan III from which an actual test program could be conducted under the cognizance of SSD/Aerospace.

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Subsequently, the AMR and PMR Range Safety representatives further agreed that the recommendations of the ad hoc committee would define the requirements for a test program to determine the hazard classification of the solid propellant motors as used in the Titan III vehicle system. (See Appendix A.)

The five members of the ad hoc Committee whose services were agreed upon by all agencies concerned are:

1. Dr. A. B. Amster, Stanford Research Institute
2. Dr. A. M. Ball, Hercules Powder Company
3. Dr. Donna Price, Naval Ordnance Laboratory
4. Dr. R. W. Van Dolah, Bureau of Mines
5. Dr. L. Zernow, Aerojet-General Corporation

The first meeting of the Committee was held at Aerospace Corporation on 7-8 January 1963. Dr. A. M. Ball, Hercules Powder Company, was elected Committee Chairman. In attendance were representatives of Aerospace Corporation; Air Force Systems Command Headquarters; AMR; ASESB; Deputy Inspector General/Safety, Norton AFB; National Aeronautics and Space Administration; PMR; Rocket Propulsion Laboratory, Edwards AFB; SSD; and United Technology Corporation.

At this meeting it was pointed out that the primary responsibility of the Committee, as set forth in the work statement to the Committee, was to develop a minimum test plan of sufficient scope to define properly the hazard characteristics of the Titan III solid motors. Among the items to be considered in

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developing the test plan was the applicability of TO 11A-1-47 to the Titan III solid motors; the inter-relationship among critical diameter, geometry, and temperature of the solid motors; and the possible interaction between the solid motors and the liquid core.

To provide the necessary background information to the Committee, the development of the Titan III and its attendant hazard classification problems were reviewed; the current hazard classification adopted by AMR and PMR was discussed with reference to experience with various types of missile failures. Attendees were requested to provide detailed information to the Committee on the various missile failures pertinent to the problem.

Subsequently, the Committee met at AMR and PMR to review launch facilities and range safety operations, and review the various types of on-pad and in-flight failures.

A meeting was held at Aerospace Corporation on 27-29 March 1963. The Committee met in closed session 27 March and on 28 March presented the broad outline of their proposed test plan to representatives of the same organizations in attendance at the first meeting.

A final meeting was held at the Naval Ordance Laboratory, White Oak, Silver Spring, Maryland, on 14-15 June 1963. The Committee met in closed session to review and approve the final draft of the report.

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GENERAL CONSIDERATIONS

The hazard potential of the Titan III solid motors revolves primarily around the question of the explosive potential of the solid propellant in the size, geometry and condition as manufactured, and as modified through catastrophic incidents. One obvious question concerns the basic detonability of the system. Is the propellant detonable under foreseeable conditions? If so, what conditions and what stimulus are required? The air blast and fragment hazards are then reasonably predictable. If not detonable, what air blast and fragment hazards may be anticipated?

The approach taken by the Committee has been to consider the incidents that may occur with reasonable probability and the potential consequences of these incidents in causing a catastrophic explosion or in modifying the basic potential hazards of the Titan III solid motors. Based on these considerations, a test program is proposed to define the potential explosion hazard of these motors.

The Committee was requested to consider the applicability of TO 11A-1-47 in assessing the hazards of solid motors of this size and the effect of varying solid motor parameters such as geometry, propellant formulation, etc. The Committee feels that TO 11A-1-47 is inadequate because of the impossible number of trials and attendant costs before results of reasonable reliability are attained by the go-no-go approach. The Committee feels that minor changes in grain configuration, propellant formulation, and number of segments offer only second-order uncertainties. Obviously, a major change in propellant formulation would require a complete reappraisal of the program of hazard evaluation.

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Based on discussions at Aerospace Corporation, Atlantic Missile Range, and Pacific Missile Range, the Committee believes that the incidents enumerated below will have a sufficient probability to warrant consideration. The list is only illustrative; it is not intended to be all-inclusive for the Committee does not feel competent to imagine all possible incidents, nor to assign probabilities to the incidents selected.

1. One or more segments may become involved in a general fire during shipping and handling.

2. Ignition of the motor during assembly may occur.

3. The solid-motor-liquid engine (dry) assembly may topple during erection and transport to the launch pad.

4. After charging with liquid propellant, a liquid propellant fire may result from faulty plumbing or rupture or perforation of liquid propellant tanks, or from premature functioning of the liquid engine destruct system.

5. The solid motor destruct system may operate prematurely on the pad.

6. One solid motor may fail to ignite at launch.

7. Premature functioning of the solid motor destruct system immediately after launch may result in a fallback onto the pad. Simultaneous malfunction of guidance and destruct systems may result in earth impact under power. In either case, the liquid propellants may explode.

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8. A fallback may occur in such a manner that the liquid propellants do not explode, but that the solid propellant is shattered and subsequently ignited.

9. A powered impact may result in which the solid propellant shatters and is partially confined by penetration into the earth.

These postulated incidents will now be examined individually in order to delineate areas of ignorance and to draw up a proposed test plan.

1. Fire in Shipping or Handling - Previous experience with similar, though smaller, systems as well as static firing of this unit, has demonstrated that a sound fuel-binder composite propellant, when ignited, will only burn. A porous fuel-binder propellant may burn to detonation. Porosity in the propellant therefore constitutes an important possible source of difficulty. It is evident that proper inspection which will detect and prevent shipment of porous grains is highly desirable. The Committee recommends assignment of Explosives Hazard Class 2, without further testing, to segments which do not have adverse acceleration or cold temperature history. In this and subsequent recommendations of assignment to Class 2, the Committee considers the material to present a fire hazard only.

2. Fire During Assembly - The same considerations apply in this case as in Case 1, with further hazard if the unit is propulsive. The Committee recommends examination of the assembly process with particular

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emphasis on restraints, and the assignment of Explosives Hazard Class 2 without further testing.

3. Toppling of a Solid Assembly With or Without the Unfueled Liquid Rocket - If toppled, the solid motors will fracture. In the absence of ignition, there appears to be no immediate explosive hazard. Under some circumstance, however, as when the motors are completely assembled or the nozzles installed, ignition may render the system propulsive. The latter set of circumstances may result in an airborne stage which, crashing into the ground at a distance from the site of the accident, would present more serious consequences. This latter situation is considered in Case 8.

4. Liquid Propellant Fire on Pad - It is reported that the critical diameter of a fuel-binder propellant decreases with increasing temperature of the propellant. In the worst possible case, prolonged exposure to the liquid propellant fire could heat that portion of the propellant next to the case to a temperature at which the critical diameter would be small enough to be initiated from the destruct system or other explosive ordnance present. Examination of this case requires answers to a series of questions:

   a. After what exposure would the solid propellant ignite and make the motor propulsive?

   b. What are the possible and probable time-dependent temperature profiles of the propellant under such exposure?

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c. What is the critical diameter-temperature relationship of the propellant?

d. What is the shock sensitivity-temperature relationship of the propellant?

5. <u>Solid Motor Destruct Premature on Pad</u> - It is essential in this case that the solid destruct system render the solid motors completely non-propulsive. Assuming no propulsiveness, but ignition of the solid propellant, resulting fire may cause structural failure of the liquid tankage, allowing the liquid propellants to contribute to the fire. This case then becomes the same as Case 4.

If, however, activation of the solid destruct results in separation and propulsiveness of the solid motors, they may follow an unguided course in any direction. This can then become the same as Case 8.

6. <u>Failure of One Solid Motor to Ignite</u> - At worst, this incident could result in toppling of the assembly followed by powered impact of the ignited motor if it should separate from the remainder of the assembly. These cases are discussed below.

7. <u>Effects of Explosion of Liquid Propellant</u> - Two cases may be visualized in which the possibility of an explosion of the liquid propellant should be examined.

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These conditions presume a failure of the destruct systems and result in:

a. Impact with the ground under fallback conditions, implying rupture of tankage and mixing of the hypergolic propellants at low velocities and with little or no confinement.

b. Powered impact with the ground, implying violent rupture of tankage and turbulent dynamic mixing of the propellants, possibly under some confinement accompanying partial penetration into the ground prior to mixing.

Hypergolic liquid propellant systems such as the ones under consideration have been studied extensively. All of the available evidence suggests that ignition occurs very quickly and prior to massive mixing. This effectively prevents massive mixing by blowing the hypergolic ingredients apart. Experiments to date have been carried out either under essentially static conditions or under conditions such as might be expected with Case 7a, namely fallback from a very low altitude.

Fallback from great heights, or worse yet, powered impact (Case 7b), represents more extreme circumstances. Although the hypergolic nature of the propellants may still prevent massive mixing which effectively avoids conditions that might lead to detonation even under dynamic conditions, this question is of sufficient importance to require verification; the answer can have a significant bearing upon the total explosive yield from the system when the solids are taken into account.

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Important questions which should be answered are the following:

a. Does the dynamic impact provide opportunities for turbulent mixing, which can appreciably change the mass mixing prior to hypergolic ignition?

b. Can additional confinement (accompanying earth penetration) occur rapidly enough prior to hypergolic ignition to permit greater mixing and therefore greater explosive yields from the hypergolic liquids?

c. Is there any other way in which the dynamic impact might result in massive mixing and subsequent detonation?

If there are circumstances under which it can be demonstrated that hypergolic liquid propellants can be made to detonate, they must then be evaluated further to determine whether or not they can, in fact, act as suitable donors for initiating the solid propellant. Under these conditions, the significant questions are:

a. What is the pressure-time stimulus which the liquid donor can provide to the solid propellant?

b. Is the solid propellant sufficiently sensitive to be initiated?

c. Is the solid propellant geometry such that, if initiated, the detonation can propagate into a substantial portion of its mass?

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It is of importance to point out that while the TNT equivalent of a given propellant system is a useful criterion for assessment of the blast damage potential of that system, there is no reason to expect that identical propellant formulations will show identical TNT equivalents in different systems. In other words, the TNT equivalent is definitely not an intrinsic property of a propellant composition in systems whose propellant geometry is sub-critical.

8. Fallback, Fracture, and Subsequent Burning of Solid Propellant - It is known that a porous solid propellant charge can burn to detonation. It is possible that impact on steel, concrete, or earth may cause significant porosity in the propellant grain. Even if detonation does not result, burning into the porous material may cause an explosion whose damage potential at a distance is comparable to that of a detonation. Investigation of this case requires an answer to this question:

   a. Under what conditions will impact result in sufficient additional reactive surface to present a blast hazard?

   Ignition is assured in this case, either from the functioning of the destruct system, or from the liquid propellant fire resulting from the fallback.

9. Powered Impact, Solid Motor - In the case selected, it is assumed that the destruct system of the liquid core has malfunctioned and the vehicle falls in a fireball of burning liquid. In addition it is assumed that the solid destruct system has not functioned, and that shortly before impact

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the vehicle disintegrates leaving the solid motor to impact separately from the liquid engine. The areas of ignorance are those of Cases 4 and 8.

On the basis of the evidence available to the Committee, the maximum impact velocity was qualitatively chosen as 900 feet per second. However, it is desirable that this velocity, V_O, be estimated more quantitatively on the basis of Titan III estimated performance. The velocity should be calculated as that velocity attainable with 50 percent of the solid propellant remaining in accordance with the standard calculations for computing Instantaneous Impact Points as used by the Ranges. It is the opinion of the Committee that impact velocity for test purposes should not exceed 900 feet per second.

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CONCLUSIONS

The points raised in the previous discussions can be classified into three major areas in which questions exist whose answers are essential to the hazard evaluation.

I. The physical behavior of large solid propellant masses under conditions of impact, leading to fracture and non-detonative reactions which can contribute to blast effects.

II. The critical diameter, critical geometry, and sensitivity characteristics of solid propellants as functions of temperature and modification of the physical structure, e. g. , fracture, cracking, and induced porosity.

III. The dynamic behavior of hypergolic liquid propellant systems, and their assessment as potential donors.

It is now useful to take each of these three areas individually, and to design experiments which will provide meaningful answers to the questions raised.

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TEST PLAN

I. PHYSICAL BEHAVIOR OF SOLIDS

A. Concept

There exists a large amount of data on the physical properties of solid propellants of the type planned for the Titan III motors, but essentially all of this data has been obtained at low rates of loading in tension, compression, and shear. Similarly, the reaction of solid propellant motors to stresses of pressurization or impact after short falls is generally known. The behavior of solid propellants to stresses caused by very high rates of load is inadequately known. High-amplitude compression waves interacting or followed by rarefaction waves or high-amplitude shear waves can cause disintegration of propellant. Even should detonation of the propellant not occur as the result of this complex shock loading, the modified propellant may be made susceptible to initiation to detonation by subsequent shocks. Further, if the propellant is broken up sufficiently, mere deflagration on the greatly increased surface can result in a substantial contribution to the resulting blast. The test plan must explore both the nature and extent of the breakup under possible conditions, and also the air blast effects subsequent to this breakup.

In the program that follows, certain tests are proposed with inert propellant having physical properties as similar to the Titan III propellant as possible but with the ammonium perchlorate replaced with an inert salt. These tests are designed to facilitate a study of changes in the propellant grain, ranging from

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crazing through fissuring and actual breakup. Similar tests with live Titan III propellant will allow an assessment of blast effects from deflagration or detonation. Scaled motor tests are proposed to allow prediction of behavior of full Titan III scale and larger motors whose adequate testing is not feasible.

B. Test Plan

1. Propellant: Inert formulation with physical properties of Titan III propellant and normal Titan III formulation.

2. Geometry: Hollow, right cylinders with the O.D./I.D. equal to 3 and L/D equal to 1 and 5. Thus a Titan III segment and a 5-segment motor are approximated. (See Figure 1.)

3. Size: Diameters of 2, 6, and 18 inches chosen to divide the range into three sizes; the largest diameter is nearly 10 times the smallest.

4. Motor Case Wall: Thickness to be scaled as $t = \frac{(.35)(\text{Test diameter, inches})}{120 \text{ inches}}$, to model the Titan III solid motor case.

5. Impact Velocity: V_o, $\frac{1}{3} V_o$, $\frac{1}{9} V_o$ feet per second. Nine hundred feet per second (V_o) was deemed a reasonable estimate for maximum velocity the motor would have on fallback or powered impact subsequent to early failure.

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6. Target: Two types of targets will be used in order to encompass the extremes of deceleration and confinement.

   a. Sand targets will be used for low deceleration and high confinement.

   b. Steel targets backed with concrete will be used for high deceleration and low confinement.

   As an alternative to the impact of motors on these targets, particularly with large motors at high velocities, impact of steel plates on the motors can be considered. The effect of the obvious differences in pressure-time history must be established.

7. Attitude: Normally end-on but with enough trials side-on to demonstrate any possible differences.

8. Instrumentation: All tests should be instrumented for air blast and burnout time, with pressure-time measurements being taken both close to, and at a distance from the charge. In addition, radiation measurements and high-speed photography coverage should be provided. Where feasible, in-target pressure-time measurements should also be undertaken.

Should the above program give only minimal air blast effects from live motors, the following extension should be considered. The motors, fired end-on, should be tail-end fused with an impact-resistant fuse having a delay time approximately equal to twice the shock transit time in the propellant.

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The booster charge of 1/3 of the web thickness and 2 diameters (of the booster charge) long should be used. The booster should be located on a radius and centered on the web. (See Figure 2.)

Additional information of value could be obtained in the following supplemental program. Slabs of live and inert propellant, 2 and 6 inches thick (simulating webs of two larger motors above) and 3T inches square (T = web thickness), are shocked simultaneously from both sides by properly attenuated shocks from sheet explosives. After one- and two-shock transit times, a 1/3 T diameter booster, 2 diameters long, is fired. The sheet explosive charges are simultaneously initiated along one edge with live initiators. The attenuators are of a thickness necessary to reduce the shock pressures to those estimated as resulting on impact at velocities listed in Paragraph 5 above. (See Figure 3.)

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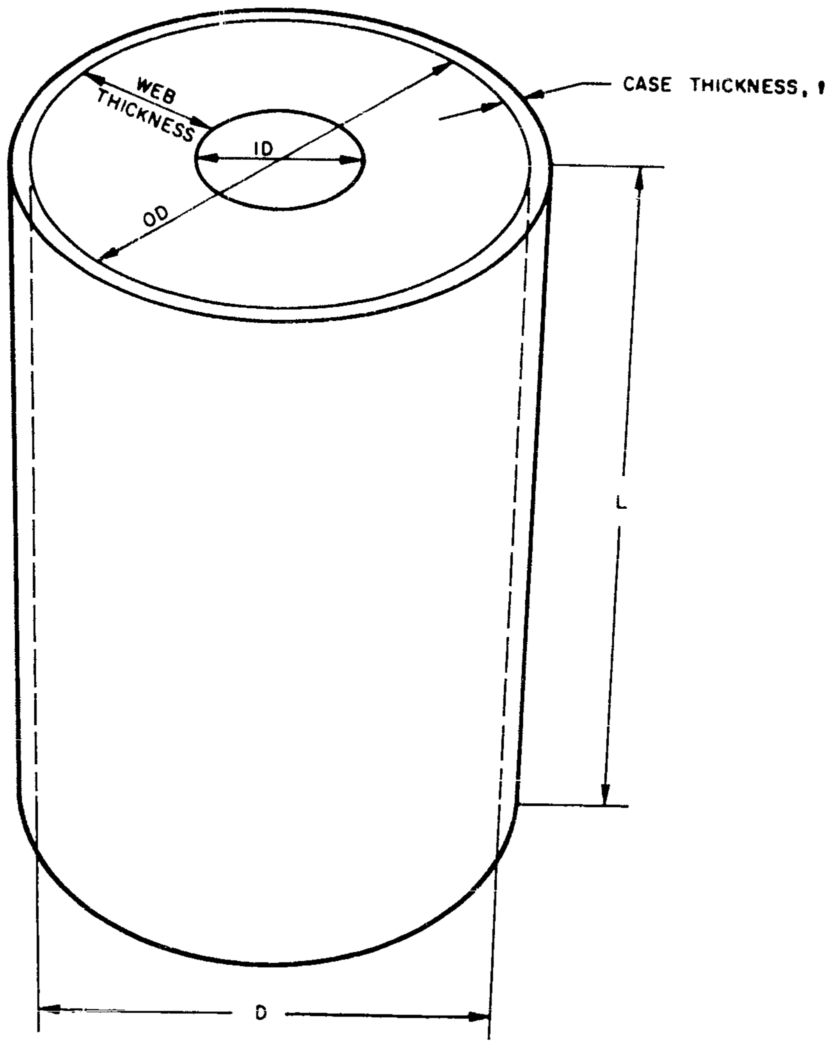

FIGURE 1

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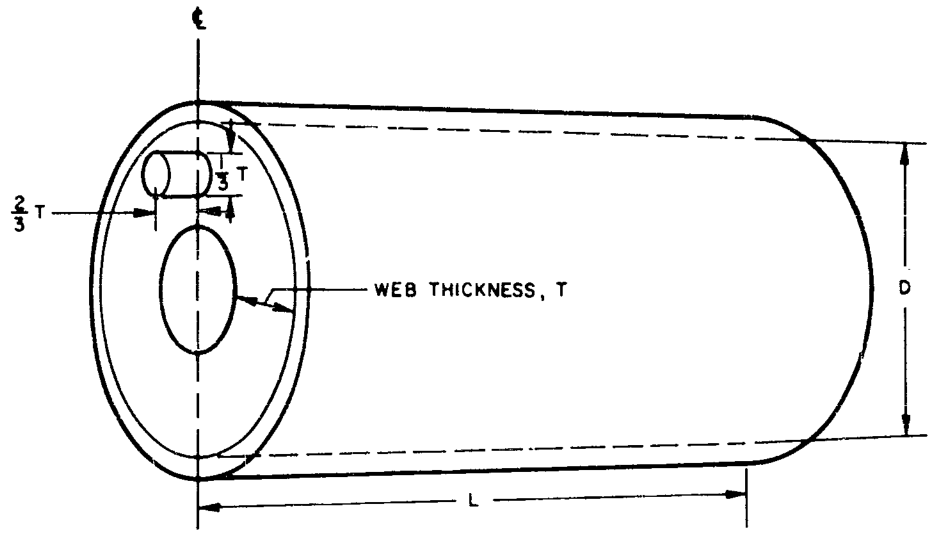

FIGURE 2

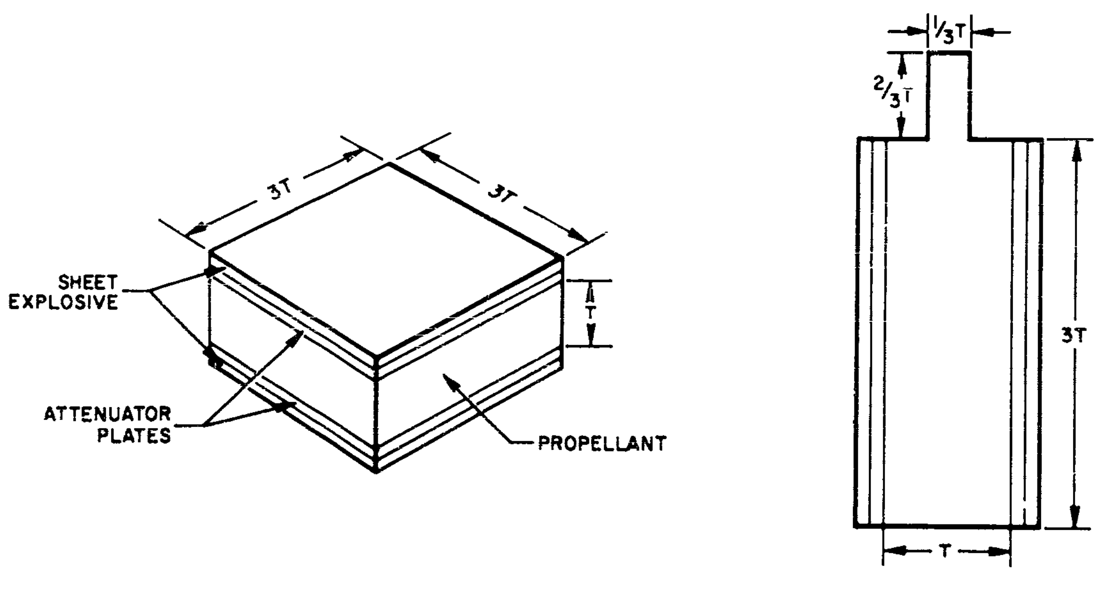

FIGURE 3

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II. CRITICAL DIAMETER, CRITICAL GEOMETRY, AND SENSITIVITY

A. Concept

The ability of an acceptor to respond to a detonative initiation is in part limited by the size and shape of both the acceptor and the donor explosive. Most existing data apply to the case of end-initiation of solid cylindrical acceptors, for which there exists a "critical diameter" below which detonation does not propagate in the acceptor. The critical diameter of solid fuel-binder propellants is known to exceed 20 inches. Actual propellant systems of interest are rarely found in the simple solid cylindrical form, nor are the locations of regions of possible initiation uniquely defined as they are for the "critical diameter" determination.

The "critical diameter" concept must therefore be extended to encompass more realistic shapes other than simple cylinders. The extended concept is called the "critical geometry" concept.

It is clear that the extension of the simple concept introduces some new complications such as:

1. The arbitrariness of the point or points of initiation.

2. The possibility of partial propagation of the detonation in geometrically favorable regions, followed by fading or extinction of the detonation in geometrically unfavorable regions.

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These two complications can have a major bearing upon the questions of sensitivity (as based upon the minumum size of initiating charge) and upon the yield, which depends upon the amount of propellant consumed in the detonation.

The Titan III solid motor can be approximated by a hollow cylindrical propellant configuration.

It has been reported that critical diameter decreases with increasing temperature. This information suggests the possibility of a real case wherein an insensitive explosive (fuel-binder composite propellant at normal temperature) is surrounded by a shell of sensitive propellant (the same propellant at high temperature). Detonation of the sensitive layer may be expected to result in a major contribution from the surrounded insensitive material to the resultant air blast.

In Section I of the Test Plan the possibility is explored of a broken-up propellant burning to detonation. A sufficiently subdivided charge can also respond to detonative initiation and would presumably have a critical diameter dependent on the state of subdivision.

Finally, every explosive has a shock sensitivity that can now only be determined in samples that are larger than critical. This sensitivity is a function of temperature.

The test plan for critical geometry and sensitivity must therefore explore:

1. The critical diameter of Titan III propellant as a function of temperature.

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2. Critical geometry as a function of shape and location of donor.

3. Critical diameter as a function of active surface.

4. Shock sensitivity as a function of temperature.

In addition to these more basic determinations, the program should also include

1. Critical web thickness for hollow cylinder, and

2. Explosive blanket experiment, to demonstrate the contribution of insensitive propellant to the air blast from a detonating outer layer.

B. Test Plan

In the several series of tests, the parameters chosen should be explored over the ranges shown. All charges should be cased in steel cases having approximately 1/4-inch wall thickness.

1. Critical Diameter versus Temperature

a. Diameter of propellant samples:
1-inch, 2-inch, 4-inch, 8-inch, 24-inch, 48-inch

b. All samples to have L/D = 4.

c. All donors to be full diameter and L/D = 2.

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d. All large donors to be initiated at multiple points on donor surface as necessary to approximate a plane wave.

e. Temperature range to be 400°F and lower.

f. Tests should be instrumented to provide velocity as well as witness data.

In order to assure the acquisition of appropriate thermal data and equilibrium attainment, inert samples of propellant (of appropriate sizes to match live samples) will be instrumented with the thermocouples to determine the time required for temperature equilibrium.

Some live propellant samples are to be instrumented with thermocouples in order to obtain information about possible exotherms at the higher temperatures.

In all cases, heated samples of propellant will be examined macroscopically as well as microscopically and by X-ray for evidence of physical changes caused by the thermal conditioning. The macroscopic examination will also include tests (sensitivity and critical diameter) on samples of live propellant exposed to typical thermal histories and subsequently cooled to, and conditioned to, 25°C. The objective is to ascertain whether the heat treatment can induce physical and chemical changes, which would cause the observed change in critical diameter.

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2. Critical Geometry Experiments

a. To avoid expensive large-scale experiments with hollow cylinders, two experimental techniques should be considered:

1. Th sting propellant composition could be used at that elevated temperature at which it has previously been determined that 8-inch diameter charges are above the critical diameter.

2. A propellant formulation containing added HMX or other suitable material could be prepared with characteristics such that it has a critical diameter of approximately 8 inches at ambient temperature.

b. Hollow cylinders of L/D = 1 and O.D./I.D. = 3 will be prepared with web thicknesses initially of 8 inches.

c. End initiation will be studied.

d. Starting with an 8-inch web thickness on the acceptor and an 8-inch diameter donor of L/D = 2, find minimum donor diameter that will result in propagation in the 8-inch web.

e. With a donor of L/D = 2, and donor diameter equal to web thickness, the acceptor web thickness will be reduced, keeping acceptor L/D = 1, and acceptor O.D. constant until a minimum web thickness is determined.

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3. Critical Web Thickness for Hollow Cylinder

This experiment is designed to answer the questions:

What is the critical web thickness W_c for side initiation of a hollow cylinder, composed of a propellant whose critical diameter is D_c?

What is the minimum explosive charge required to side-initiate a hollow cylinder of critical web thickness W_c?

a. The same propellant charges will be used as in Item 2 above.

b. A donor of cylinderical form L/D = 2 will be used.

c. The choice of experimental technique involving either elevated temperature or an HMX modified propellant formulation as is indicated in Paragraph 2a, is again available.

d. The donor will be shaped to conform to the cylindrical surface of the propellant charge. It will be placed in contact with the propellant by means of an appropriate aperture cut in the confining case. It will be located at the midpoint of a cylindrical element of the case. The initial donor diameter will be 8 inches.

4. Effects of State of Subdivision on Critical Diameter

a. In order to study interconnected porosity, subdivided propellant prepared in mono-disperse size ranges will be used to prepare

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propellant solid cylinders of varying densities and diameters. Critical diameters will be determined as a function of porosity and particle size. Donor L/D = 2, and D donor equal D acceptor.

b. In order to study the corresponding behavior of non-interconnected porosity, attempts will be made to introduce controlled amounts of bubbles of controlled sizes into propellant samples prior to curing, and to freeze the bubbles in place during curing. Critical diameters will again be determined as a function of porosity and bubble size. Donor L/D = 2, and D donor equals D acceptor.

c. The studies described in a and b will be carried out at ambient temperature.

5. Shock Sensitivity versus Temperature

a. Sensitivity experiments should be carried out at diameters near the ideal diameter in order to avoid sensitivity variations in the non-ideal region. Since the ideal diameter is not known for the propellant under consideration, the following guidelines are recommended:

(1) Experimental diameters should be at least twice the critical diameter.

(2) Further guidance should be obtained from an experimental determination of the relationship between detonation velocity and charge diameter at a single specified elevated temperature.

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b. Cellulose acetate or lucite card gaps are recommended but other materials whose Hugoniots are well established may be used.

c. L/D = 4 for acceptor.

d. Attenuator diameter to be 1.5D.

e. Witness plate to be 3-inch to 1/4-inch steel, varying with diameter of sample.

f. Acceptor to be instrumented with probes.

g. Blast measurements are to be made if the terrain permits.

6. Explosive Blanket Experiment

a. Sample outer diameters: 2-inch, 6-inch, 18-inch.

b. O.D./I.D. = 3.

c. Length: L/D = 1

d. Explosive Blanket Thickness = 0.1-inch, 0.3-inch, 0.9-inch.

e. Initiation Modes:

(1) Point initiation midway between ends

(2) Line initiation parallel to axis

(3) Simultaneous peripheral, at one end.

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f. Instrumentation:

(1) Blast gages

(2) Solid or hollow rods in center of cylinder.

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III. DYNAMIC BEHAVIOR OF HYPERGOLIC LIQUID PROPELLANT SYSTEMS

A. Concept

The program of Section II is designed to find out whether, given a donor, the solid propellant in Titan III can be made to detonate. It is necessary to determine whether there is present an explosive donor sufficiently powerful to initiate the solid to detonation. The existing liquid propellant system has the required energy, but this energy can be released explosively only when the fuel component and the oxidizer component are intimately mixed. Existing data indicate that these two components cannot be extensively mixed because they react very quickly on first contact. Existing data were obtained under essentially static conditions; dynamic conditions may provide an opportunity for more extensive mixing.

The test program should answer three specific questions:

1. Does the dynamic impact cause turbulent mixing and an appreciable change in the mass mixed prior to hypergolic ignition and explosion?

2. Can an impacting system be confined rapidly enough prior to hypergolic ignition to permit greater mixing and, therefore, result in greater explosive yields from the hypergolic liquids? In short, how is the blast affected if the impacting system buries itself, partly or completely, in sand?

3. Can this exploding system serve as a donor for the solid motors?

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B. Test Program

The objective of the test program is to determine the maximum explosive yield possible from an incident involving the hypergolic core. The proposed tests consist of impacting a projectile against a target. The projectile will be a scale model of the Titan III liquid core first stage complete with hypergolic liquids.

1. Target:

    a. Steel backed by concrete (for all projectiles).

    b. Sand (for projectiles with D = 0.5 and 1.0).

2. Projectile:

    a. L/D, same as Titan III liquid core 1st stage.

    b. D equal to 0.5, 1.0, 2.0 feet

    c. D equal to 4 feet if deemed desirable.

3. Attitude:

    a. For D = 0.5, head-on and tail-on

    b. For D greater than 0.5, use mode giving higher explosive yield.

4. Propellant: Live

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5. Velocity:

a. At V_o for all diameters

b. At $\frac{1}{2}$ V_o for D = 2 feet

Where V_o is highest reasonably attainable up to 900 feet per second.

6. Instrumentation:

a. Pressure - Time

(1) Within the liquid

(2) Near and for field air blast

b. High-speed cameras

c. Radiant energy emission ve   s time.

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GENERAL RECOMMENDATIONS

I. Implementation of Test Plan

The Committee believes that the success of its test program depends in major part on the appointment of a competent test program director. The director would be empowered to consult or contract with any agency or contractor before, during, and after the testing period. It is, for example, the director's responsibility to see that the experimental programs have the advantage of theoretical guidance and to request or contract for expert consultation, computation, and other services necessary for this purpose. It is further his responsibility to see that all parts of the contracted work are carried out in a thoroughly integrated, comprehensive program so that each part may benefit from the results of the others as soon as they are available. The director is also to choose competent deputies to be responsible for the detailed direction of the tests, changes in specific values of the testing parameters as indicated desirable by the early results, reduction and interpretation of the data, and, above all, meeting the objectives of the program as set out by this Committee. In particular, it is the director's responsibility to decide whether full-scale tests should be made and, if so, how many. Because the Committee felt it was completely impossible to meet its objectives with a restricted number of tests (full-scale or otherwise), it has proposed a number of experimental programs. These may fulfill the objectives without any full-scale tests or with an extremely small number of full-scale tests. In view of the numerous and great practical difficulties as well as the inordinate expense of full-scale testing, no such test should be planned unless it offers an obvious benefit in meeting the program objectives. The decision, based on all the preceding work, is to be made by the director.

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II. Research Program

Although the present program is designed to lead to satisfactory answers to some Titan III problems and to point out general methods for solving future related problems, it will certainly not suffice for all future problems. To avoid future ad hoc solutions, i. e., to obtain the background for satisfactory predictions of potential hazards in the unforeseen future situations, the Air Force, perhaps jointly with other interested DOD, NASA, and AEC agencies, should initiate and continue support of a long-range research program in this area. Many topics need to be investigated.

For application to mammoth solid propellant systems, the following items seem minimal:

1. Effect of impulsive loading of solid propellants over a range of amplitudes to find effect on fracture and subsequent effect on burning rate and initiation of detonation. This would include studying plastic-elastic and visco-elastic behavior of propellant.

2. Investigation of factors influencing critical diameter for detonation in heterogeneous (separate fuel and oxidizer) systems. Definition of the exact role played by particulate mixture ingredients in modifying detonability of these systems in contrast to decomposition (detonative) of pure organic high explosive, conceivably a unimolecular process. Role of confinement in detonability and critical diameter. Work on the critical diameter theory for a fuel-binder composite propellant

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should be continued until it reaches at least the semiquantitative stage of the accepted theories applicable to organic high explosives.

It cannot be emphasized too strongly that critical diameter studies imply scaling of the explosive donor. As the critical diameter increases, the scaled donor rapidly exceeds the largest donor to be expected in the rocket. In other words, the actual physical disposition of the propellant and the potential shock loading to which it might be subjected diverge so widely from the critical diameter geometry that a better experimental route to explore potentially hazardous reactions should be found. In particular, both theoretical and experimental studies should include at least consideration of all shock-induced reactions (most of them short of detonation) of importance to safety.

3. Investigate the air blast effects from violent, but non-detonative, deflagrations of solid propellants in order to compare them with the well-established blast parameters from detonating explosives. This should be done both experimentally and theoretically. In the former, pressure-distance and pressure-time curves at various distances could be obtained for (a) a series of calibrated shock loadings of the propellant, and (b) a series of calibrated break-ups of propellant before it is strongly shocked. For both series, probe and camera coverage could be used to follow the behavior of the receptor after ignition and the extent to which it is consumed in the shock-induced reactions. The theoretical work would probably involve modifying present numerical

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programs used to compute air shocks and the following gas flow so that they could be used to compute the disturbance as a function of the rate of the energy release.

III. Destruct System

The intimate relationship that exists between the performance of the destruct system and the hazard resulting from a malfunction either at launch or in the early flight phase, suggests that additional analysis of the requirements of destruct systems should be made--especially for systems containing very large propellant masses. The requirements for large systems may differ considerably from those currently accepted for smaller systems.

Examination of proposed systems such as Titan III indicates that:

1. The propellant masses are becoming large enough to cause serious destruct effects on malfunction, even if they do not detonate.

2. The destruct system, if properly designed, may be able to contribute to a substantial diminution of this hazard, but if not properly conceived, can in fact increase the hazard.

Consider for example the case in which the destruct system only shatters or fractures the propellant. The subdivided propellant may be expected to be more sensitive to initiation and perhaps to become detonable at a smaller critical diameter, especially if the fractured propellant returns to the ground in a generally coherent mass.

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In hybrid systems such as the Titan III, it would also appear useful to evaluate the destruct design considerations which would minimize the chance that the liquid propellant fire could engulf and fall with the solid systems, thereby heating them to a potentially dangerous temperature.

These elementary considerations represent only a small part of the analysis of destruct design philosophy which, it is believed, should be re-examined in some detail, particularly in the light of this Committee's report on the hazard assessment.

IV. Interim Assignment of Hazard Classification

The following interim hazard classifications are recommended for Titan III:

1. Solid motor segment: Class 2.

2. Solid motor during assembly: Class 2.

3. Solid motors assembled and mated to liquid-fueled core, without liquid propellants on board and/or safe-and-arm devices installed: Class 2.

4. Solid motors assembled and mated to liquid-fueled core, with liquid propellants on board and/or safe-and-arm devices installed: Class 10.

These assignments may be changed as a result of the data obtained from the recommended test plan.

In the relaxation of classification, the possibilities of detonation should be viewed in the light of stimuli available.

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THE NAVY's INTEREST IN THE COMPATIBILITY OF LIQUID AND SOLID PROPELLANTS ASHORE AND AFLOAT

by
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Approximately one year ago, the development of pre-packaged liquid propellant missiles had progressed to the point where units of two designs, BULLPUP and SPARROW, could thereafter be expected by the fleet. It was planned that as liquid propellant units became available, the solid propellant units in service would be replaced, either on a scheduled basis or as consumed in the course of normal practice operations. In either case, it was apparent that both liquid and solid propellant units would be in service for an extended period of time.

Prior to the pre-packaged concept for liquids, the Navy had, for the most part, favored the use of solid propellants; this decision being based, in part, on the difficulties normally associated with the storage and handling of liquids in bulk form. Difficulties such as those encountered in the filling of power plants at a launching site were prohibitive for such operations afloat, hence, in view of this the first echelon of fleet missiles, including TERRIER, TARTAR, POLARIS, SIDEWINDER, SPARROW, BULLPUP and ZUNI were designed to employ solid propellants. The one possible exception to this philosophy was the TALOS missile which has a solid propellant booster and a liquid fueled ram jet sustainer.

With the advent of the pre-packaged liquid propellant concept, much of the apprehension toward liquid propellants was dispelled. This concept gave promise of attaining a degree of simplicity comparable with that of solid propellants with a minimum of in-service problems, together with instant readiness and high reliability. Further, the employment of liquid propellants, particularly for air launched missiles offered certain operational advantages, one advantage being that the liquid propellant engine is relatively immune to ambient temperature changes. This is particularly important for air-launched missiles, which may be carried by aircraft in flight for extended periods of time.

When the pre-packaged liquid concept was accepted for service use, questions were advanced, regarding the employment of pre-packaged missiles, either by themselves, or in conjunction with solid propellant units. Typical questions were:

1) **Would the pre-packaged missile be inherently safe;**

2) Would liquid and solid propellant units be entirely compatible, permitting completely integrated stowage and handling operations;

3) If not entirely compatible, would some degree of compatibility be possible if certain restrictions were imposed, as, for example, if certain stowage arrangements only were permitted;

4) Regardless of the degree of compatibility, would additional safety procedures and devices (increased area venting, increased sprinkling system capacity, etc.) be advisable, and

5) Could operating personnel be convinced that additional hazards would not be introduced through simultaneous employment?

Assuming that such questions could be answered readily, Coast Guard Regulations, including those promulgated as late as 1 August 1962, prohibited, in essence, the placing of liquid and solid propellant missiles together in the same shipboard compartment. Although these regulations would not be binding upon combatant ships, they would be binding upon various units of the Military Sea Transportation Service in its fleet supply functions. It was considered necessary to determine if these regulations were, in fact, realistic. If it was determined that they were not, could sufficient evidence be presented to justify their revision?

In view of the questions pending, three investigations were initiated at the Naval Weapons Laboratory, Dahlgren, Virginia in 1962. One considered the prepackaged concept only and determined that the first echelon of missiles employing this concept (SPARROW and BULLPUP) were sufficiently safe for fleet employment if certain recommended stowage conditions were met.* The second investigation considered the compatibility of liquid and solid propellant missiles; compatibility implying that the hazard potential associated with the mixed handling and stowage operations would not exceed, to any significant degree, those of independent operations. It was recognized at the outset of this investigation that mixed handling and stowage operations could result in hazard conditions equal to, or greater than independent operations. On the other hand, it was recognized that mixed handling and stowage operations could result in conditions less hazardous than independent operations. The latter could be possible because of the high "heat sink" capacity of the pre-packaged engine and because of certain possible shielding benefits of one type on the other.

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*Recommendations were presented in NWL Rpt. Nos. 1715 and 1745.

Initially, interest in compatibility was centered on the BULLPUP air launched missile. An examination of the conditions under which all air launched missiles are stowed and handled ashore and afloat (examples of which are shown in Figures 1 and 2) indicated that the greatest potential hazard influencing compatibility would be that of chain ignition, or the tendency for a conflagration to propagate from unit to unit throughout a stowage or handling area. Assuming that a hypergolic fire developed within such an area, or that a missile propulsion unit became accidently ignited, it is readily conceivable that units not involved initially could ignite as a result of the impingement of high velocity, high temperature gases on, or into, these units. Numerous systems have been developed, as shown in Figure 3, to prevent chain ignition, including magazine sprinkling, water injection, magazine venting, plenun chamber and ducts, shielding, and protective closures and containers. In addition to these measures, consideration is normally given to the geometrical arrangement of the stowed units within a magazine and to the segregation of unlike propellants.

The compatibility investigation was planned around the stowage of air launched missiles aboard carriers, and those geometrical magazine arrangements were selected that appeared most critical with respect to the chain ignition potential. The representative magazine arrangements considered are shown in Figures 4 thru 9. In general the objectives of these arrangement selections were:

1) To determine whether motors and engines are compatible in the same compartment if segregated and separated by flame shields;

2) To determine the qualitative and quantitative effects of an ignited solid propellant motor on other solid and liquid propellant units and warheads;

3) To determine emperically, the magnitude and significance of the reactions of exhaust gases of simultaneously ignited liquid and solid propellant units, if any reactions were to be expected;

4) To determine qualitatively the effect of a burning liquid propellant engine on other liquid and solid propellant units and warheads all at the closest proximity to each other:

5) To determine qualitatively and quantitatively the effect of a burning solid propellant motor on other solid and liquid propellant units and warheads, all at the closest proximity to each other; and

6) To determine the effects of various rates of simultaneous leakage of propellants from a "dual leaker" on other liquid engines, solid-propellant motors and warheads attached to the same stanchions.

To determine whether the results of a given test would or would not support the compatibility of liquid and solid propellants, it was decided that the results would be examined in the light of certain specific standards. These standards would consider, primarily, whether units did or did not chain ignite, and the relative times of ignition. It was forseeable that it might be necessary, in some tests, to consider also the "degree of violence" of the reaction of a liquid unit vs a solid unit and to weigh this factor along with the relative time of ignitions. Some indication of the degree of violence of a liquid unit vs a solid unit would be obtained at comparative tests with each progressed; and would be obtained in terms of the effect of the burning liquid or solid unit on adjacent units, i.e., the temperature rise of passive motors, engines, and warheads. Tests were planned to permit a comparison under similar environmental conditions.

In planning the compatibility investigation, it was assumed that at least the following minimum safety systems and equipment would apply to integrated stowage:

a. Magazines used for mixed stowage would meet all requirements for protective devices and damage control equipment currently applicable to solid propellant rocket motor magazines and, in addition, would meet all such requirements currently applicable to magazines in which liquid propellant rocket engines are stowed.

b. Only production motors and engines of designs which have satisfactorily passed qualification tests pertaining to safety features would be subjected to mixed stowage.

c. Solid propellant rocket motors would be equipped with thrust neutralizers (non-propulsive attachments) while in mixed stowage, since this is the characteristic method of stowing most air launched missile motors.

d. Initiators would be removed from liquid propellant rocket engines prior to stowage in a magazine, and the initiator opening would be plugged since this is the intended procedure in stowing liquid propellant engines.

e. Liquid propellant rocket engines would be provided with a leak-indicating coating, or equivalent means of detecting leaks at an early stage, as has been proposed.

The propulsion units selected for the investigation were the BULLPUP ASM-N-7 rocket motor Mk. 8, Mod 1, with a cast double base solid propellant, and the BULLPUP ASM-N7a prepackaged liquid propellant engine XLR 58-RM2, employing MAF-1 and IRFNA as shown in principle in Figure 10. The simulated stowage space used for the investigation consisted of a cylindrical chamber of 7" steel plate, approximately 22' in diameter and 9' high as shown in Figure 11. A standard shipboard sprinkling system and a 2' x 2' vent opening were provided. Engines, motors and simulated warheads were positioned. in most cases, in modular stowage system hardware, as would be employed in a carrier magazine. Representative test set-ups are shown in Figures 12 through 14. To simulate the accidental leakage of a liquid propellant unit, thus producing hypergolic fires, propellants were either spilled together on the deck from hinged containers, as shown in Figure 12 or into a specially constructed tank as shown in Figure 13 (designed to simulate a leaking engine) from which the propellants would drip onto other units. To simulate the effects of accidental ignition of a propulsion unit by impact, stray electrical sources, etc., units were ignited by standard igniters or special initiators. Warheads were included to obtain advanced data in connection with an anticipated subsequent investigation considering all-up BULLPUP stowage.

Results of the compatibility investigation were extremely favorable as presented in NWL Report No. 1832, with only one chain ignition occuring. This involved the arrangement of a liquid propellant engine with the initiator opening unplugged within a hypergolic fire, causing the pressurizing grain to ignite. A chain ignition did not occur in a subsequent test when a live initiator was installed in the opening. Maximum magazine temperature and pressures of 2500° F and 21 psi, respectively, were developed.

In general it was concluded that for the family of missiles of which BULLPUP is representative, liquid and solid propellant units are compatible even to the extent of placing dissimilar units on the same stowage stanchions, with the chain ignition hazard potential being no greater for integrated conditions than for segregated conditions. Over and above those precautions and equipment normally employed for segregated operations with either propellant type, no additional safety measures or equipment are required.

The results of the compatibility investigations were forwarded by the Bureau of Naval Weapons to the Chief of Naval Operations. It is anticipated that these results will be considered, together with the results of the third, current investigation to determine those changes desirable in operating policy and procedure. In the

current investigation, the safety aspect of storing and handling missiles as all-up, fully assembled rounds is being considered. The following changes in policy are forseeable, should the results of the three investigations prove favorable:

1) all-up round operations may be permitted for air launched missiles to decrease the strike-up time.

2) the integration of liquid and solid propellant air launched missiles may be permitted to conserve stowage and handling space and to permit random loading on magazine-to-flight deck conveyor systems. One such conveyor system is now in use with others contemplated in the future.

In addition to having an influence on combatant vessel operations, it is likely that the results of the compatibility investigation will also be considered during the next revision of the Coast Guard Rules and Regulations for Military Explosives and Hazardous Munitions (CG 108).

The need for additional effort in certain areas has been indicated by the investigations mentioned as well as other investigations conducted to date. These areas are not related to integrated operations alone but are, for the most part, associated with independent liquid propellant or solid propellant operations. Some effort, for example, is indicated in determining the best location for sampling tube intakes for the toxic vapor detector systems, and in determining the effects of tube length and circulation within a stowage magazine on detector response. A review of the presently accepted minimum concentration levels for stowage areas (.5 ppm for MAF, 5.0 ppm for IRFNA) appears desirable in order to determine if these levels are realistic. The response of detectors to vapors other than those of the liquid propellants, such as produced by solid propellants, paints, etc. is an area for further investigation. Additional effort appears warranted in developing equipment and procedures for the removal and disposition of leaking engines, in providing adequate magazine ventilation, in perfecting leak indicating paints, and, in the continued development of protective clothing.

Efforts are currently in progress in connection with most of these problems at various naval establishments.

Integrated liquid and solid propellant operations are being considered for missile families other than air launched missiles. For example, the liquid propellant Powered Target, KD2B will be

employed in the present TERRIER MARK 10 Launching System, with target rounds interspersed between missiles in the magazines of this system.

Efforts such as the compatibility investigations mentioned in this paper should facilitate an orderly transition by the fleet from the use of one propellant type to another. In so doing, restrictions will be removed which should permit an increase in operational flexibility. Finally, interest by the Navy in such an investigation represents another step toward the safer employment of missiles by our Armed Forces, both ashore and afloat.

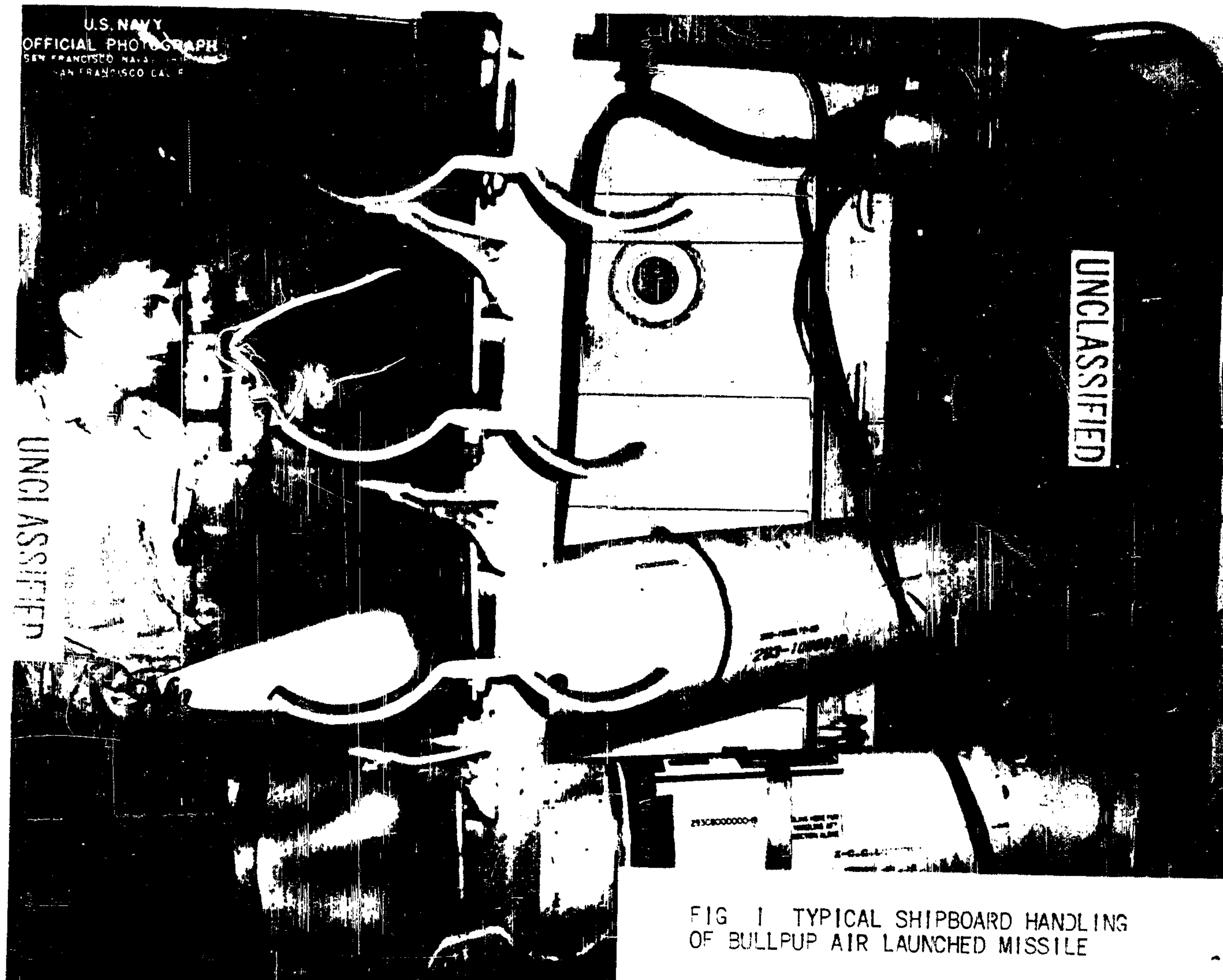

FIG. I TYPICAL SHIPBOARD HANDLING
OF BULLPUP AIR LAUNCHED MISSILE

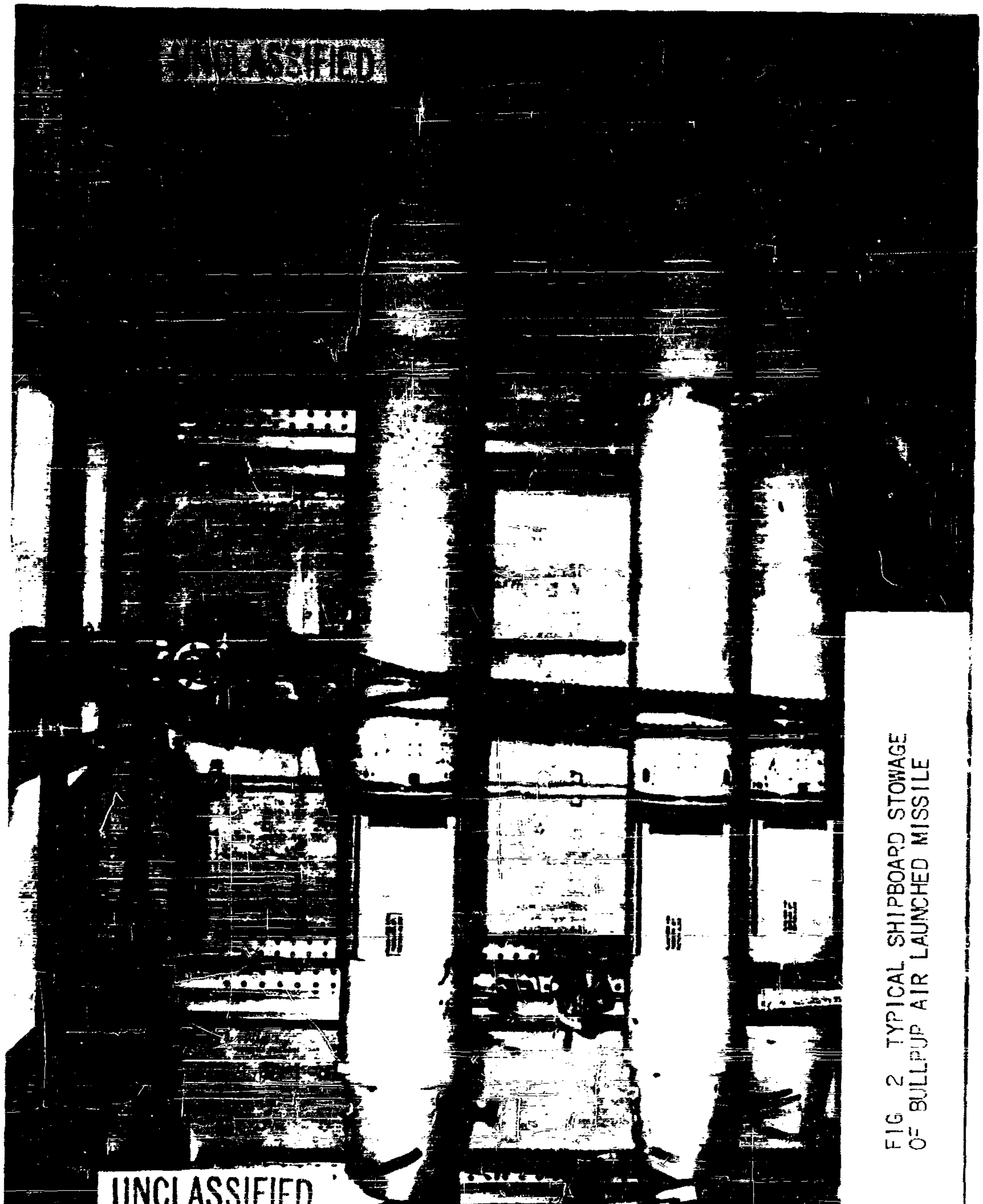

FIG. 2 TYPICAL SHIPBOARD STOWAGE
OF BULLPUP AIR LAUNCHED MISSILE

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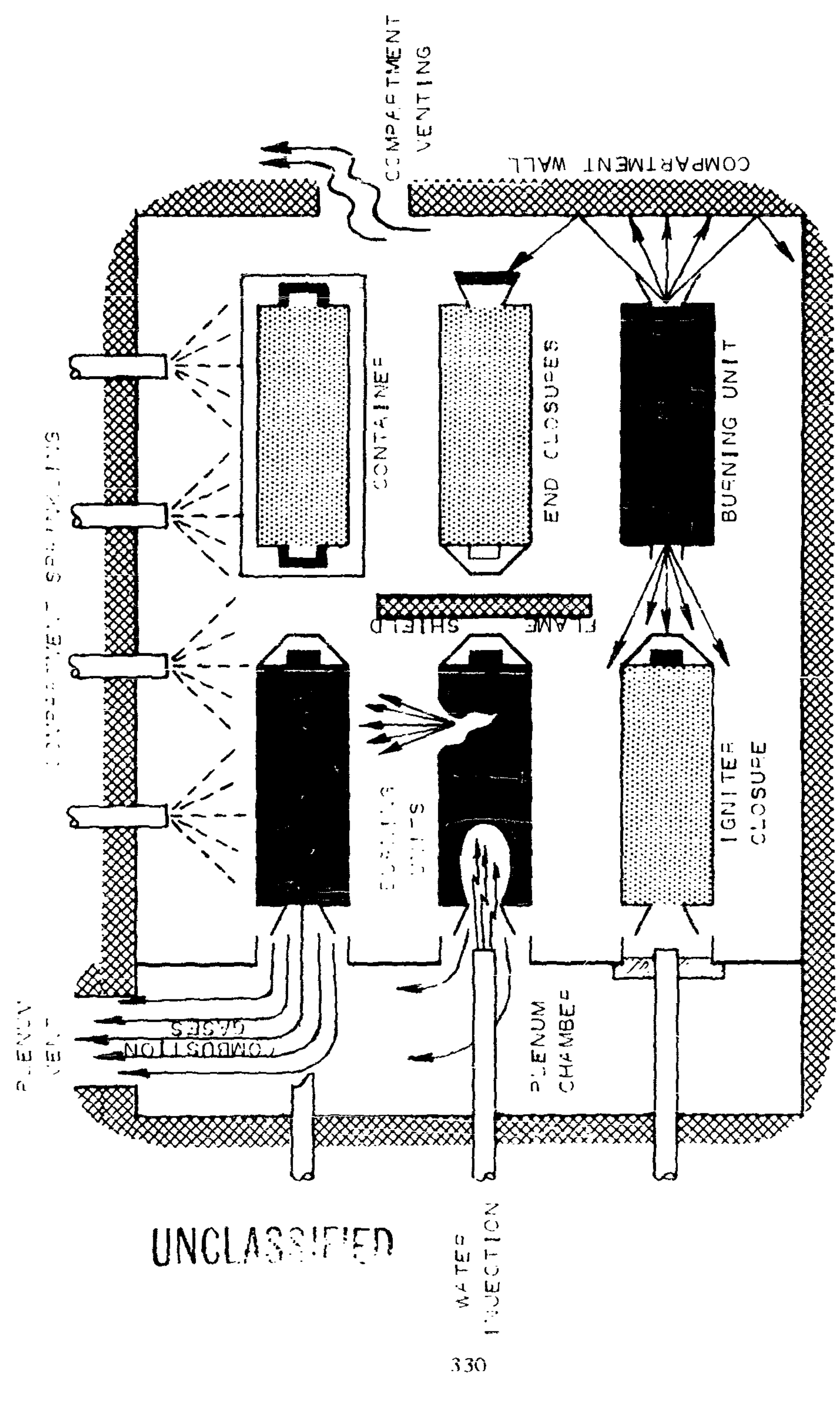

FIG 3
REPRESENTATIVE SAFETY SYSTEMS

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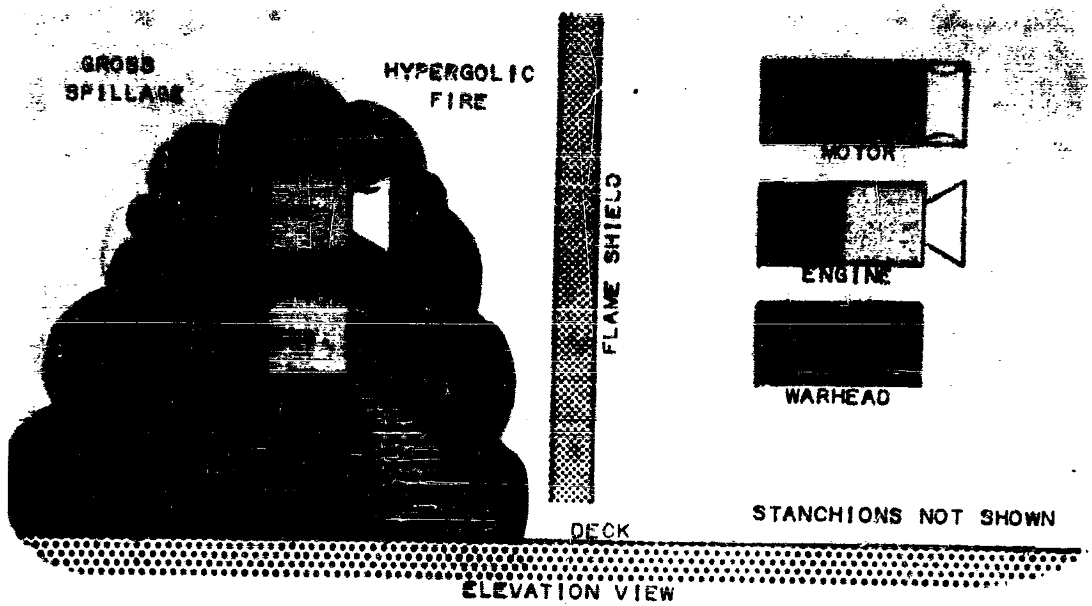
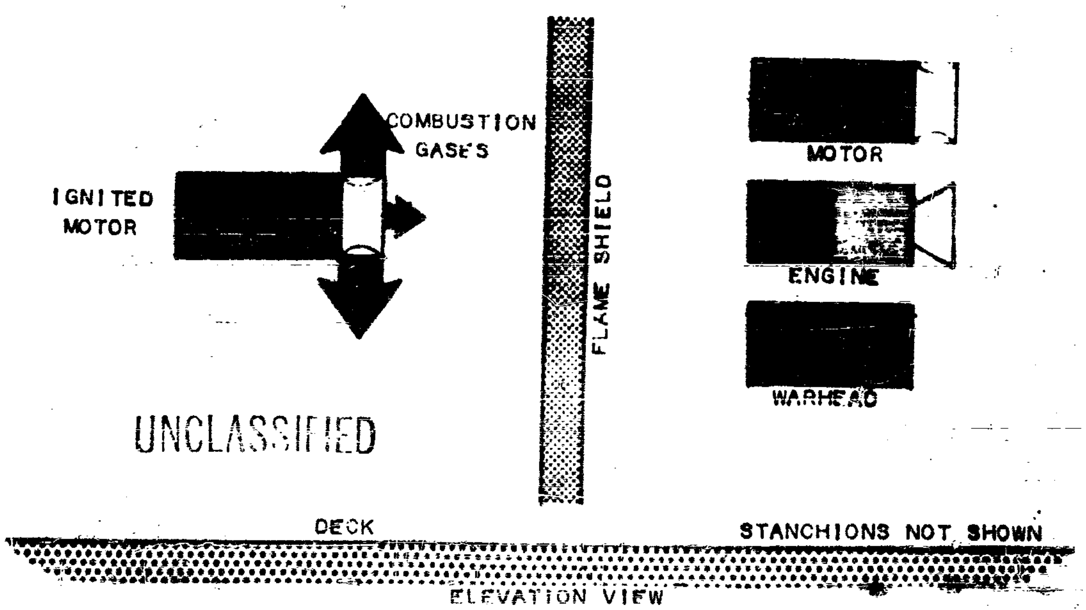


FIG 4 EFFECTS OF HYPERGOLIC FIRE ON COMPONENTS IN STOWAGE

FIG 5 EFFECTS OF ENVIRONMENT OF BURNING UNIT ON OTHER COMPONENTS



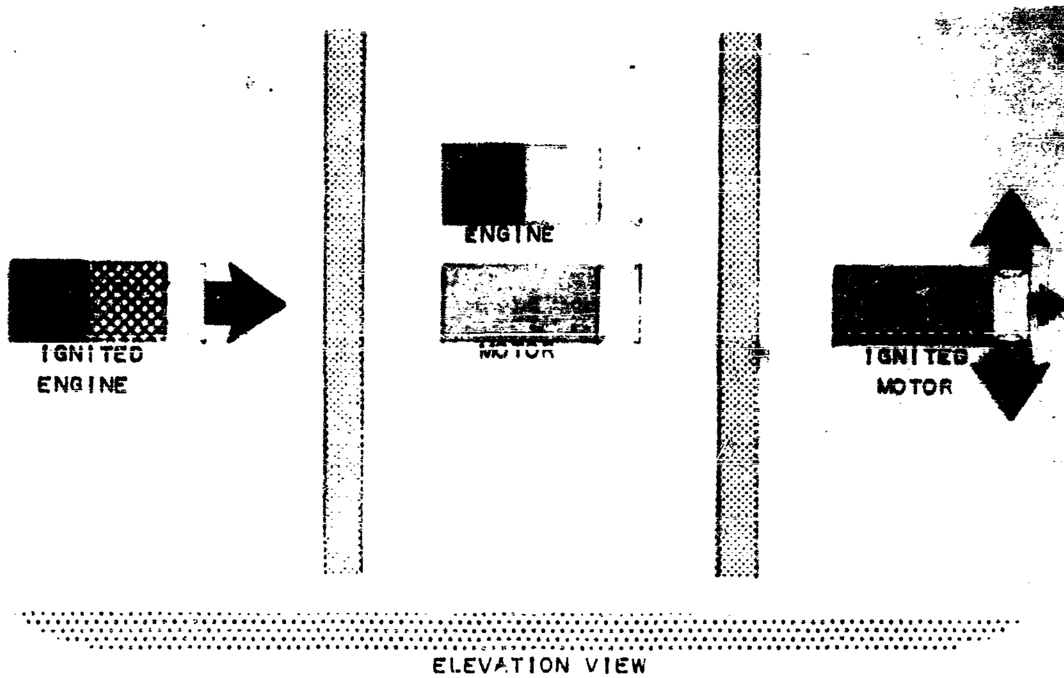


FIG 6 POSSIBLE INTERACTION OF COMBUSTION GASES AND EFFECTS

FIG 7 FURTHER STUDY- HYPERGOLIC FIRE, MIXED MISSILE STOWAGE

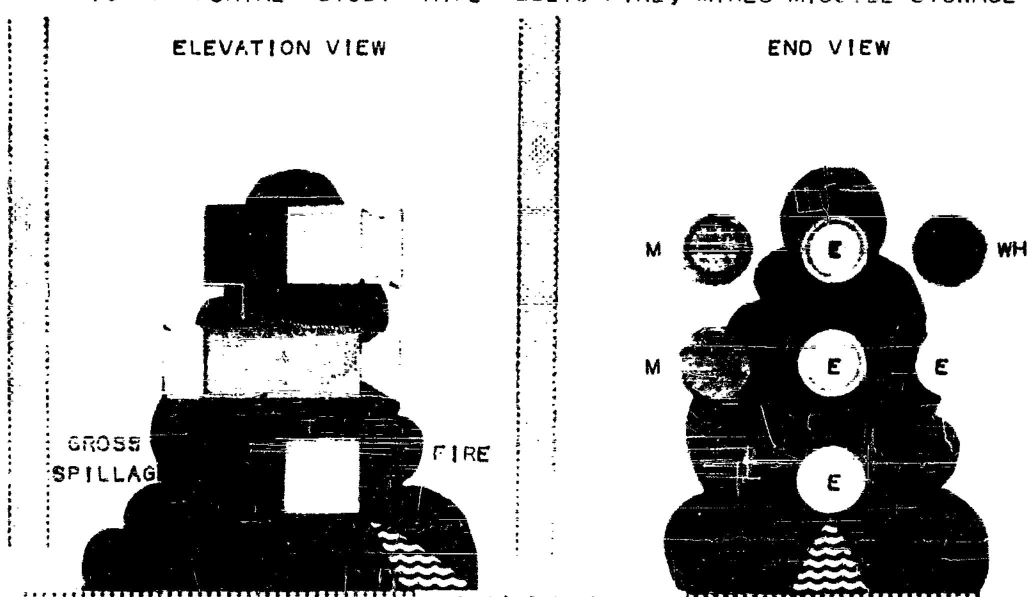


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FIG [illegible] EFFECTS OF DI[illegible] ON COMPONE[illegible]

FIG 9 EFFECTS OF SLOW-LEAKA[illegible] ON OTH[illegible]

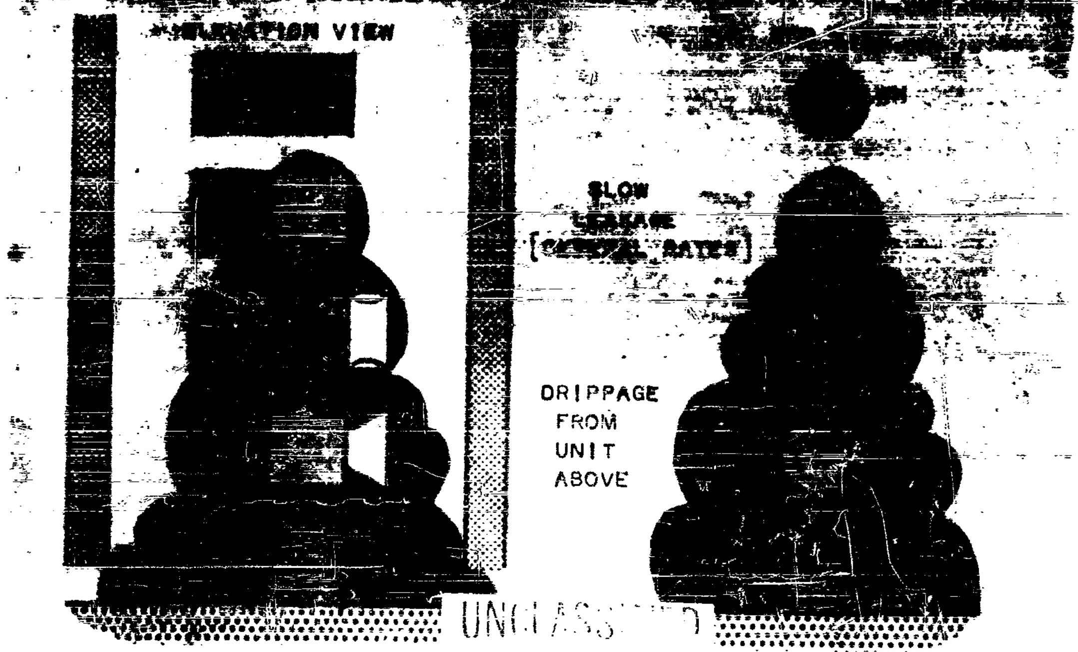

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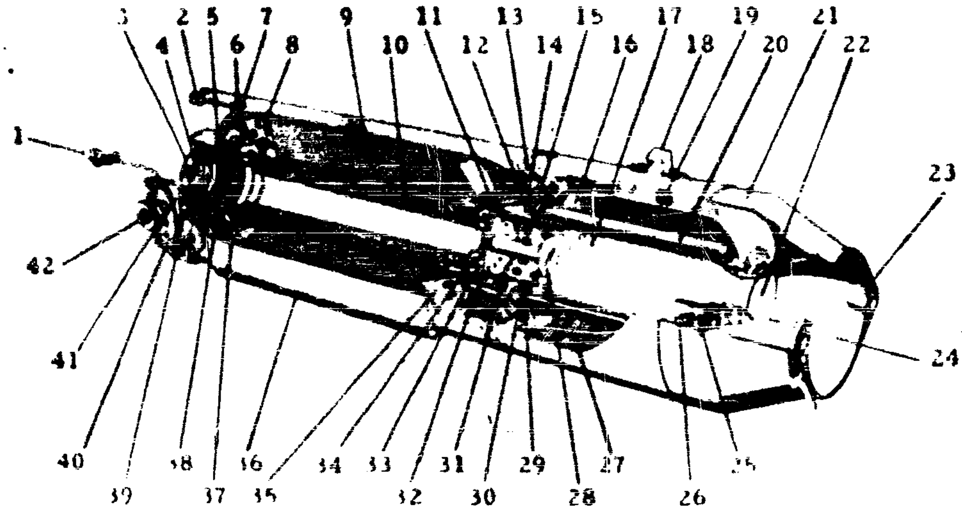
Figure [illegible] Isometric of Sectioned LR58-RM-4 Rocket Engine



1. Electrical connector
2. Interrupted splice joint
3. Cap and housing assembly
4. Igniter boost charge
5. Adapter and liner assembly
6. Seal cap
7. Plug, oxidizer tank
8. Diffuser and deflector
9. Oxidizer tank
10. Solid propellant charge
11. Director and screen assembly
12. Orifice, gas generator tube
13. Header
14. Shear slide
15. Burst band, fuel tank
16. Diffuser assembly
17. Combustion chamber
18. Launching lug
19. Aft slot cushion
20. Screen and baffle assembly
21. Fairing cone
22. Plug, nozzle
23. Parasitic flare strap
24. Nozzle
25. Flare boss
26. Plug, fuel tank
27. Fuel tank
28. Pintle
29. Orifice, fuel
30. Shear cup
31. Orifice, oxidizer
32. Spacer, shear slide
33. Retaining ring, shear slide
34. Retainer, solid propellant charge
35. Baffle, tank
36. Wing slot
37. Spacer, solid charge
38. Burst band, oxidizer tank
39. Igniter
40. Igniter housing
41. Safety switch and resistor
42. Cap and flag assembly

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FIG. II 2700 CUBIC FOOT CHAMBER USED AS A SIMULATED SHIPBOARD MAGAZINE FOR LIQUID-SOLID PROPELLANT AIR LAUNCHED MISSILE COMPATIBILITY TESTS

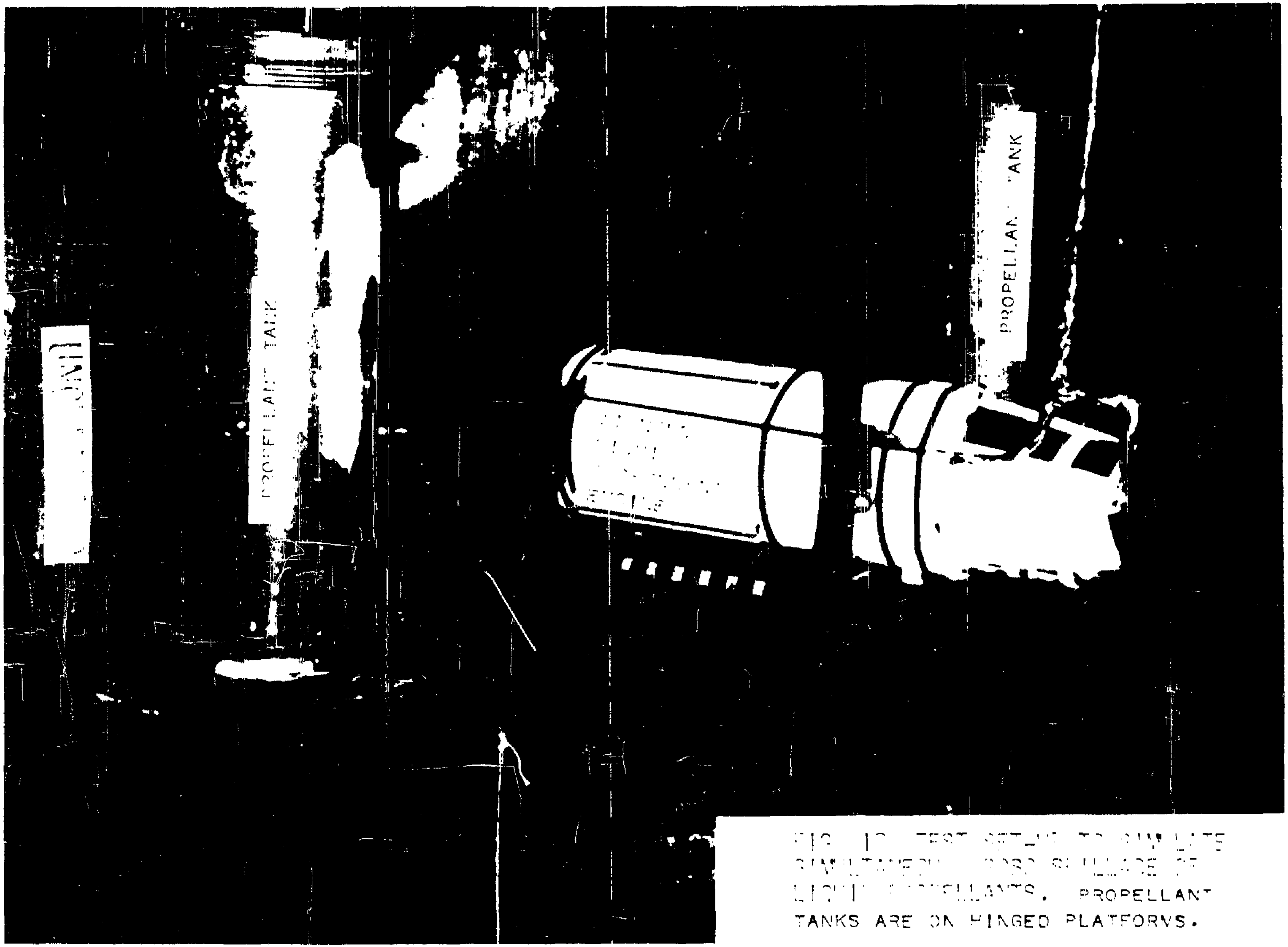
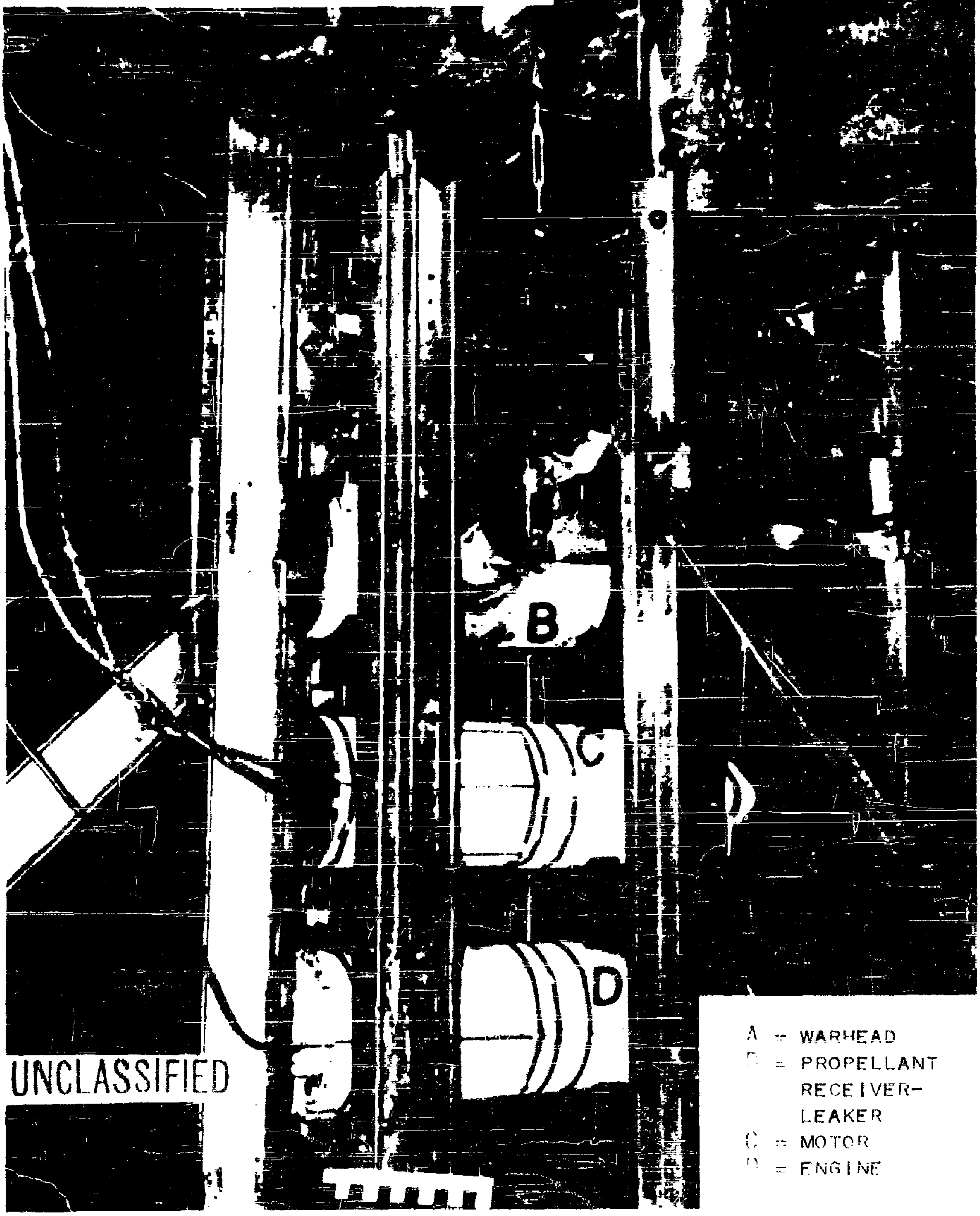


FIG. 1[illegible] TEST SETUP TO SIMULATE SIMULTANEOUS CROSS SPILLAGE OF LIGHT PROPELLANTS. PROPELLANT TANKS ARE ON HINGED PLATFORMS.

FIG 13 TEST SET-UP TO SIMULATE RELATIVELY SLOW SIMULTANEOUS LEAKAGE OF PROPELLANTS



A = WARHEAD
B = PROPELLANT RECEIVER-LEAKER
C = MOTOR
D = ENGINE

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FIG 14 TEST SET-UP TO DETERMINE EFFECTS OF ENVIRONMENT OF A NORMALLY BURNING UNIT ON OTHER COMPONENTS IN STOWAGE

A = MOTOR
B = ENGINE
C = WARHEAD
D = DONOR MOTOR

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INCIDENT INVOLVING N_2O_4 + NO AND FUEL OIL IN A WASTE DISPOSAL SYSTEM

by
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One of our most critical problems at Thiokol's Reaction Motors Division at Denville, N.J. is disposition of waste propellants. Our facilities are located in a watershed area, and our activities involving use of propellants are closely monitored by concerned authorities. Although we are engaged in working with solids, our principal activities are in the liquid field with disposal sometimes being quite a problem. Those of you familiar with liquid systems realize that during test programs bleeding and venting of propellants is practically unavoidable, and can involve the dumping of considerable quantities of propellants during operations.

During the past few years, Thiokol-Reaction Motors Division has been conducting a test program involving the use of N_2O_4 + NO and MMH as a propellant combination.

Since this is a hypergolic combination, we felt that by venting and bleeding the fuel and oxidizer into a common open receiver, economical and expeditious disposal would be effected. Unfortunately, this system gave us a fume problem, and was discontinued in favor of separate means of disposal for the fuel and oxidizer. Although this presentation concerns the oxidizer side, I would note that the disposal of the MMH was, and is, no problem; the fuel being dumped into an open pot of burning JP fuel or simply collected in a drum and carted away.

After much thought and study, it was decided to effect the disposal of N_2O_4 + NO by collecting the waste in a tank, and vaporizing it into a stack and oil burner system. The burner was set fuel rich, the principal being that the N_2O_4 + NO vapors would react with unburned fuel vapor.

As you can see, the system was quite simple, consisting of a collector tank, a fire box, and stack, and a conventional oil burner unit. One-fourth inch vent and bleed lines connected the test stand system with the 25 gallon stainless steel collector tank which in turn had a 3/4 inch line leading to the fire box. A 1/4 inch vent line was run from the collector tank to a point approximately 100 feet to the rear of the area.

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The burner chamber and collector tank were enclosed in a shroud of sheet metal to aid in heating the collector tank during winter operations, the aim being to vaporize the N_2O_4 into the fire box where it would burn off.

The system described was not of the system which was destroyed but of an earlier similar system installed and successfully utilized for over a year prior to the incident which occurred with the second system.

While the first system was used as a model for the second, there was one significant change. The inlet line to the fire box was positioned slightly above the burner in the first set-up while in the unit involved in the incident, the inlet was below the burner.

Now that the set-up has been described, I will proceed to the incident involving the second set-up.

The system was installed on November 1962, and used without incident until March of 1963. On the 27th of that month at approximately 8:45 p.m., the collector tank exploded. Prior to the explosion, the engine system had been bled down, and five engine firings made without venting the test stand tanks. The oxidizer tank was being operated at 700 psi and immediately upon venting after the fifth run, the collector tank exploded. The oil burner had been turned on at about 4:30 p.m. of the 27th, and was known to have been operating at the time of the incident.

Fortunately there were no personnel injuries although shrapnel did damage some wiring in the area. There was very little fire following the explosion, and operating personnel had no difficulty securing the area.

Observation immediately after the incident revealed the fire box and stack to have been tossed about 20 feet from its original position and the collector tank to have disappeared.

The following morning, a search was made for pieces of the collector tank with about 1/3 of the tank being recovered. All parts located were extremely distorted, and showed a minimum amount of stretch marks, indicating a detonation of high order magnitude rather than a gradual over-pressurization. Most of the parts found were rather small, a further indication of an almost instantaneous break-up of the tank. In addition, the violence of the explosion is further attested to by a piece of the tank entering the burner stack. This piece entered at an almost flat angle, gouged its way for approximately four inches before penetrating the 1/2 inch steel stack.

There was no definite pattern as to where the tank parts were blown to, however, one fragment weighing about 1 lb. was found approximately 1000 feet from the site of the explosion.

Most of the pieces located were from the girth of the tank and showed traces of carbonaceous material. In addition recovery and analysis of sections of the 3/4 tubing leading from the collector tank to the fire box revealed the presence of fuel oil and/or the products of reaction of fuel oil with N_2O_4 + NO.

As a result of our investigation, we believe that the detonation occurred when a surge of pressure was applied to the collector tank when the test stand tank was vented after the fifth run. We feel that the collector tank contained a shock sensitive mixture of methylene chloride (used as a flushing solvent in the engine oxidizer system), N_2O_4 + NO, and hydrocarbon. Methylene Chloride was periodically flushed through the engine system and collected in the collector tank through the bleed lines. The presence of hydrocarbon can be explained as follows: During operation of the burner, the collector tank was heated to vaporize the N_2O_4 + NO. Upon shutdown, the collector tank colled, and in doing so, sucked in residual flue gases and traces of fuel oil.

This would be particularly true during winter months since during cold weather ice could have formed in and plugged the 1/4 inch vent line which as I mentioned earlier ran from the collector tank to a point some 100 feet to the rear of the setup. With the vent line clogged, the only inlet for pressure equalization during cooling of the collector tank would be through the 3/4 line through which the N_2O_4 + NO vapor was fed to the burner. As I mentioned previously, this line entered the fire box at a point below the burner and any oil leaking would easily enter the line.

To further substantiate our belief that fuel oil and/or oxidation products were present in the tank involved is the result of an analysis of the contents of the collector tank in the first system, that is the one shown in the slides and which we had operated for approximately a year prior to the second system incident. This analysis revealed the presence of fuel oil and products of the reaction of fuel oil with N_2O_4 + NO.

Trauzl block tests as conducted to determine the sensitivity of fuel oil with N_2O_4 + NO showed results as tabulated below.

SENSITIVITY OF FUEL OIL N_2O_4 + NO MIXTURES IN THE TRAUZL BLOCK TEST

Quantities (cc)		Expansion (cc)	Comment
N_2O_4 + NO	Fuel Oil		
3.0	0	5.0	-
1.5	1.5	-	Completely destroyed block
2.5	0.5	-	Completely destroyed block
2.7	0.3	-	Blew hole in side of block
2.8	0.2	42	-
2.9	0.1	12	-

In all cases a No. 8 blasting cap was used as the initiator and a total of 3 cc of mixed liquids was used. It is to be noted that mixtures quite oxidizer rich were still very sensitive.

Similar tests were conducted on mixtures of methylene chloride and N_2O_4 + NO with the following results:

SHOCK SENSITIVITY OF METHYLENE CHLORIDE - N_2O_4 + NO MIXTURES IN TRAUZIL BLOCK

Quantities (cc)		Expansion (cc)	Comment
Methylene Chloride	N_2O_4 + NO		
3	-	5	Insensitive
1.5	1.5	24	Sensitive
.75	2.25	8	Sensitive
.30	2.70	7	Sensitive
-	3	5	Insensitive

It can be concluded that methylene chloride N_2O_4 + NO mixtures can be shock sensitive. Impact tests using a drop weight tester were also conducted on the same mixtures but with different results. For example where a 50/50 mixture of fuel oil and N_2O_4 + NO tested in the Trauzil block completely destroyed the block, the same proportionate mixture gave a threshold value of 34 inches or 394 feet lbs, 2 in. indicating the mixture to be relatively insensitive to shock.

Drop weight tests on a 50/50 mixture of methylene chloride and N_2O_4 + NO gave a threshold value of 2770 feet lbs. 2 in.

Card gap tests on a 50/50 mixture of methylene chloride and N_2O_4 + NO (% by weight) showed that this mixture can definitely propagate a detonation. Standard JANAF card gap equipment was used with a card value of around 25 cards established.

It is not my intent to enter a discussion of the validity of different types of shock sensitivity testing. I merely point out differences in results, and urge that any of you engaged in testing for impact sensitivity of liquid propellants carefully evaluate your means of testing.

Since this incident, we have not used burning as a means of disposal. At present, we collect waste N_2O_4 + NO in a tank containing water which is emptied when required by a disposal subcontractor.

In closing, I would point out that we now barricade all collector tanks in our test areas and I would recommend that those of you engaged in similar operations carefully check all installations for proper barricading if you have not already done so.

Dr. Van Dolah: This is in the nature of a comment rather than a question. The drop weight test that I assume you're talking about is the Olin Mathieson test. In any case, its of no consequence. Because you can very readily fall into a trap of misinterpreting the results that one gets from any of these drop weight tests on liquids, particularly if one thinks that these are adiabatic compression tests which they aren't - especially when you have a volatile material such as N_2O_4 in the system. This does a couple of things, it displaces that atmospheric oxygen out of the system which has a profound effect. Secondly, it has an awful good heat sink capability for soaking up all of this energy and if you want to include the so-called impact sensitivity of a lot of sensitive liquids by the usual test, just add a little N_2O_4 into it, but stand back.

Mr. Hayes: I understand the Olin Mathieson drop weight tester is the only drop weight tester that is approved for liquids. The drop weight tester we use is one of our own configurations. Maybe I shouldn't say this. The results were so bad. There is a very small quantity involved, maybe 3/100 of a cc total in the cup that's used. I personally feel that the drop weight tester is not a good means of evaluation particularly with something like this.

LOW-VELOCITY DETONATION IN NITROGLYCERIN[1/]

by Robert W. Van Dolah[2/]

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The history of nitroglycerin is marred by a high frequency of disasters, beginning with the destruction of the first plant at Heleneborg, Sweden, September 4, 1864, in which Emil Oscar Nobel, brother of Alfred, and four others lost their lives (1)[3/], and continuing with the recent series of accidents that has plagued the solid propellant industry. Few would argue but that nitroglycerin is very subject to inadvertent initiation, yet nitroglycerin can, under certain circumstances, resist initiation by a blasting cap; and its card-gap sensitivity, as determined by the "standard" test, is not very much greater than that of nitromethane. This anomaly results both from some inherent limitations in the card-gap test itself, but more particularly from a lack of recognition and appreciation of low-velocity detonations (LVD), or, as they are more frequently described, low-order detonations.

The hydrodynamic-thermodynamic theory for steady-state, normal detonations is well substantiated by experiment (2). Recently the mechanism of initiation of high-order detonations by high-amplitude, large-impulse, plane shock waves has been reasonably established, both theoretically and experimentally (3,4). In contrast, LVD, though recognized for many years (5), has never been the subject of extensive investigations, either experimental or theoretical. This omission has stemmed from the general emphasis placed on the performance of explosives rather than their hazards, and the more tractable nature of the theory and the more facile the experimentation on normal detonation.

In recent years the card-gap test (6) has been widely applied to assess the sensitivity of many materials to initiation of detonation by shock. In a common version of this test, a high-velocity

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1/ This work was supported in part by the Advanced Research Projects Agency and Bureau of Naval Weapons.

2/ Research Director, Explosives Research Center, Bureau of Mines, U. S. Department of the Interior, Pittsburgh, Pa.

3/ Underlined numbers in parentheses refer to items in the list of references at the end of this report.

detonation is the only result accepted as a "positive;" all other results are deemed negative. This bias derives from the use of a steel witness plate with the requirement that a positive result be recorded only when the plate has been perforated. But nearly the same damage potential exists if the explosive accidentally undergoes a low-velocity detonation as if a normal detonation occurs.

Moreover, the "standard" card-gap test has yielded widely divergent results when simple changes were made in the acceptor container, such as substitution of aluminum tubing or even thin-walled steel tubing for the standard Schedule 40 steel pipe (nominal wall thickness of 0.135 inch). Some typical results for three materials, NG/EGDN (nitroglycerin-ethylene glycol dinitrate, 50/50 by weight), nitromethane, and Cavea B contained in steel and aluminum pipe having 0.135-inch walls, are given in table 1 (7). The original suggestion that nitromethane could be used as a standard is shown to be unworthy by the insensitivity of nitromethane to changes in the charge configuration. The card-gap value of NG/EGDN, in contrast, varies by a factor of four depending on the container.

TABLE 1. - Some representative card-gap values

	Steel	Aluminum
NG/EGDN	41	167
Cavea B 110	7.3	12.6
Nitromethane	25.2	26.6

Containers: 3 x 1 x 0.135 inch wall

Other anomalous results were encountered when still other containers such as of Lucite[4/] or Lucite-steel were used to allow high-speed photography of the initiation process. Table 2 contains some such results using 3-inch-long, round, and square containers. As is customary, the gap values throughout this paper refer to the approximate gap at which initiation (of the high-velocity detonation) is expected in 50 percent of the trials. The values in tables 1 and 2 for NG/EGDN in round steel tubes deviate one from another more than is to be normally expected in card-gap results. However, since the

4/ Trade names are used in this report for identification only, and endorsement by the Bureau of Mines is not implied.

TABLE 2. - Card-gap values for NG/EGDN vary with container

Material	Shape	Size	Gap value
Steel	Round	1.05 in.	52
Steel-Lucite	Square	.87 in.	151
Lucite	Square	.87 in.	263
Lucite	Round	.98 in.	314

All containers 3 inches long; walls 0.130-0.135 inch thick; size indicates inside dimension.

data of the two tables derive from quite different times, and because of attempts to minimize effect of uncontrolled variables, the comparisons within each table are believed to be valid.

Figure 1 shows selected frames from a shot of NG/EGDN in a 1-inch-square by 3-inch-long container having steel side walls and Lucite front and back walls. Initiation was from the shock from the usual 50-gram tetryl donor attenuated by 1.5 inches of Lucite. Time between frames is 4.2 μsec. In this case, despite the obvious violent reaction that was initiated, the witness plate was only domed--a negative result by the normal criterion used in the card-gap test. That the gap value of NG/EGDN, at least as determined in thick-walled tubes, can vary over a rather wide range has been very puzzling but, as will be described later, the variation can now be related to the initiation of LVD.

EXPERIMENTAL DETAILS

One charge arrangement used in these studies corresponds to that in the usual card-gap test, except that the length of the acceptor is increased to 16 inches, and in some cases two or four timing stations are inserted along the length of the cup to allow measurement of rates with 10-mc counterchronographs (fig. 2). The use of a lengthened acceptor charge reduces the ambiguity of results often posed by the different types of damage to the witness plate resulting from shorter charges. The witness plate is 1/4-inch cold-rolled steel; the donor is 50 grams of tetryl (1 x 1-5/8 inch); for gaps under 0.5 inch, 0.010-inch cellulose acetate cards are employed; for larger gaps, 0.5- or 1-inch-long Lucite cylinders are used alone or in conjunction with the 0.010-inch cards. The liquid acceptor charges were

contained in 1-inch tubes of steel, aluminum, copper, lead, Lucite, and polyethylene having nominal wall thicknesses of 0.035 and 0.125 inch except in the case of polyethylene which had a 0.003-inch-thick wall.

A rotating-mirror framing camera was used for a detailed study of the events; this camera is capable of providing 25-frame sequences with minimum exposure of 0.13 μsec and a minimum interframe time of 0.8 μsec. In order to observe LVD in long tubes, mirror speeds as low as 400 rps were used, giving an interframe time of 10 μsec and an exposure time of about 1.7 μsec.

NG/EGDN, 50/50 by weight, rather than neat nitroglycerin, was used because of a convenient supply of the former. All evidence suggests that the mixture behaves quite similarly to neat nitroglycerin.

RESULTS AND DISCUSSION

A high-order detonation was judged to have occurred by finding a clean-cut hole in the witness plate, by fragmentation of the acceptor cup into very small pieces, and by the rate when measured. The normal detonation rate for NG/EGDN was found to be independent of tube material and gap thickness; all results averaged 7.5 mm/μsec.

A low-velocity detonation was indicated by a shallow dome in the witness plate, by complete fragmentation of the acceptor cup into large pieces, and by rates in the range of 1.5 to 2 mm/μsec.

An earlier investigation, in which the wall thickness of the containers was varied, had shown that the limiting card-gap thickness for initiation of the high-velocity detonation in NG/EGDN was nearly the same for charges in thin-walled steel and aluminum cups. With both metal cups, the card gaps were greater for the thin-walled charges than for thick-walled charges, quite contrary to expectations if one assumes that weaker shocks would be more effective in containers providing more confinement. An important observation, however, was that in every case a so-called failure in terms of plate perforation was actually an LVD. Only rarely was non-initiation or incomplete propagation observed even with Lucite gaps as great as 12 inches!

A series of modified card-gap experiments was run in order to define the threshold gaps separating initiation of normal detonation from initiation of LVD. The up-and-down method was employed, yielding estimates of the median value of the gap thickness beyond which LVD would be expected to occur more than 50 percent of the time. Five to seven pairs of high-low results were used in each case. The

same lot of NG/EGDN was used throughout. The results are shown in figure 3. A striking increase can be seen in the limiting (50 percent point) gap for the normal detonation as steel cups of standard wall thickness are exchanged for cups of other materials of the same wall thickness. Similarly, all materials except Lucite gave greater gap values with thin walls than with thick. Perhaps the most unanticipated result was that the very thin-walled polyethylene, representing nearly a zero wall case, gave the greatest gap value of all, with the single exception of thin-walled lead. In terms of the shock pressures required to initiate NG/EGDN to normal detonation, these data indicate that smallest pressures are required with little or no confinement. The difference between the thick-walled steel and lead cups indicates that confinement, in this instance, must play quite a different role from the customary one, that is, the simulation of larger charge diameters by virtue of inertial mass.

An earlier paper (8) described precursor waves in the liquid explosive ahead of the incident shock in the liquid when the wall material had a high sonic velocity. Figure 4, taken from that paper, is a Rapitronic camera schlieren photograph (0.5 μsec exposure) of the bow waves in the body of the NG/EGDN contained in a square tube having Lucite front and back walls and steel side walls. In that paper, a mechanism of initiation involving cavitation caused by interaction of weak shocks, heating through viscous shear and rarefaction waves was suggested. Figure 5 is a very simplified representation of part of the complex of the bow waves trailing from the compression wave in the wall, the main compression wave in the liquid, a Mach stem shear wave, and rarefaction zones back of the leading bow waves and after relaxation of the compression waves at the axis. The angle of the bow wave was taken as 4 to 1, reflecting approximately the relative sonic velocities in steel walls and NG/EGDN; this angle is almost identical with that of the leading wave in figure 4. The consequences of these compression, shear, and rarefaction waves are illustrated in figure 6, which shows the pre-detonation spike in a sample of NG/EGDN contained in a Lucite tube after being subjected to a highly attenuated shock. Other similar photographs have shown the base of this conical spike to be luminous, suggesting the onset of reaction well ahead of the original shock wave in the liquid and ahead of any manifestation of high pressure. This observation corresponds to that of C. H. Winning (9), who described the onset of a delayed, high-velocity, luminous detonation within a rarefaction cloud.

The cavitation, or breakup, of the liquid that results from this complex of precursor wave interactions suggests an explanation for the peculiar effects of the walls noted in figure 2. Table 3 lists the sound velocities corresponding to thin-rod velocities, together with the card-gap values for the five thick-walled cylinders. Containers

TABLE 3. - Card-gap values related to impedance mismatch between container and Lucite gap

Material	U_s,*/ m/sec	$\frac{P_t}{P_i}$	Card gap value, inches
Lucite	1,840	1.0	3.4
Lead	1,190	1.73	3.5
Aluminum	5,000	1.73	1.7
Copper	3,810	1.87	1.2
Steel	5,200	1.90	.3

*/ Sound velocity values were obtained from Handbook of Chemistry and Physics, 44th Edition, 1962-63, Chemical Rubber Publishing Co., Cleveland, Ohio, p. 2597.

of steel, copper, and aluminum, all having higher sound velocities than NG/EGDN (sound velocity of approximately 1,500 m/sec), yielded card-gap values, defining the high- from the low-velocity detonation, substantially lower than those when Lucite and lead containers were used. The sound velocity of Lucite is only slightly higher than that of NG/EGDN, while the sound velocity of lead is less. Table 3 also includes the ratios of transmitted pressures to incident pressures at the Lucite-cup interface, obtained by using the simple acoustic approximation. For the three metals of high sound velocity, these ratios rank in the order of the relative card-gap values. The different threshold gap values for the materials suggest that the threshold exists by nature of inhibition of the high-velocity detonation. This inhibition could result from breakup of the liquid, precluding the development of normal high-velocity detonation, caused by the wall-derived precursor waves.

This peculiar role of the container in determining the character of the detonation established by a given incident shock may be regarded in the following way. If the container material has a high sound (or shock) velocity relative to that of the liquid, the strength of the initiating shock must be high and the induction period short if the breakup of the liquid is not to result from the

phenomena associated with the bow waves. The higher the shock speed in the container, the faster the bow waves will develop in the liquid, and the sooner their effects will be manifested; thus a higher incident shock in the liquid will be required to initiate normal detonation. With containers having a sound velocity just slightly greater than the liquid, such as the Lucite container, a long induction period, implying a relatively weak incident shock, is tolerable before significant breakup of the liquid occurs. If the container has a lower sound velocity, as does the lead container, there can be no bow wave ahead of the incident shock in the liquid and the LVD should not be stable. Preliminary results indicate that LVD is only marginally stable in Lucite containers. Figure 7 contains some selected frames showing NG/EGDN, in a 1 x 16-inch Lucite tube (0.06-inch wall), initiated through 4 inches of Lucite barrier by the standard 50-gram tetryl donor. A broad luminous reaction zone followed by the slow development of a cone of products can be seen. Time between frames is 30 μsec but the exposure is about 1.7 μsec, so only a little smearing at the apparent wave velocity of about 2 mm/μsec occurs. The gridmarks on the back-lighted screen are 2 cm apart. Here the progress of the front appears to be fairly uniform. Other times more instability is observed.

As the wall thickness is decreased in any of the materials, the pre-initiation waves are more rapidly attenuated. The difference between the materials tends to vanish with decreasing wall thickness, as is to be expected, converging on a single value of the gap at zero wall thickness. This value is approximated by the single point for the thin-walled polyethylene-contained charge. The higher value observed for the thin-walled lead, if confirmed in subsequent experiments, may be due to the lead providing confinement that may exert some effect at these very low shock strengths.

The initiation of LVD by interaction of weak shock waves and viscous shear heating would appear to be a direct confirmation of one initiation mechanism suggested by Bowden (10). More importantly, LVD in containers of high sonic velocity seem to provide a case comparable to that described by Bowden (11) of a deflagration coupled to a shock wave. He suggested the term "pseudo-detonation" for the deflagration of silver azide crystals, initiated by a water shock, when the crystals contained defects created by a faster shock traveling through the crystal itself.

The mechanism suggested above for the propagation of the LVD through a dispersed liquid phase brought to that condition by precursor waves in the container wall is tacitly an unsatisfactory mechanism for LVD in a liquid explosive in very thin-walled containers or in a lead container. In these cases, rarefactions from the rear and from the sides of the acceptor charge can cause cavitation in the long initiation-delay times associated with the weak shocks transmitted through several inches of Lucite.

In order to investigate cavitation caused by thin shocks, water as an inert liquid and NG/EGDN in cubical containers were subjected to attenuated shocks from small explosive charges. The containers had front and back faces of 0.25-inch Lucite and sides with 20-gauge steel. The attenuation of the shock from a tetryl charge, 2 cm in diameter and 6 mm long, was by means of a 0.75-inch-thick aluminum plate forming the bottom of the 3-inch cube; this thickness is adequate to resist penetration or spallation by the small explosive charge when backed by either liquid. Figure 8 shows water cavitating as a result of the explosive-derived shock and rarefaction waves. In the first frame shown, the incident shock had traveled through about 4 cm of liquid; a cone of bubbles associated with the rarefaction process is apparent. Subsequent frames shown in the figure are 8 μsec apart. Examination of the full sequence showed that the bubbles were first apparent about 8 μsec after the shock entered the liquid. (The dark object at the top of the frame protruding into the liquid is a pressure transducer employed in a related investigation that will be the subject of a later communication.) The cloud of bubbles that subsequently develops throughout the liquid probably results from rarefaction associated with shocks transmitted through the walls from the aluminum plate as well as those resulting from the shock in the liquid impinging on the wall.

The consequences of these shocks and rarefactions in a comparable cubical charge of NG/EGDN are shown in figure 9. In the first frame shown, the shock has proceeded nearly 4 cm through the liquid; the beginning of a luminous cone of bubbles can be seen at the bottom of the chart. Since the plate is not defeated by the explosive charge, the luminosity does not derive from luminous products of the donor. Frames taken at 8-μsec intervals were again chosen. The earliest appearance of the luminous bubbles is approximately 4 μsec after the entry of the shock wave in the liquid; these may derive from bubbles already at the bottom surface. The development of the cone of luminous bubbles in this case comes about 16 μsec after the initial shock. As with the water shot, a cloud of bubbles associated with wall-derived rarefactions can be seen. This cloud of bubbles, in the early stages at least, probably contains only reflective bubbles, with little if any chemical reaction occurring. Beside the central column of obviously reactive bubbles, a constellation of other bubbles, each growing with time, can be followed in the successive frames. Ultimately, the entire charge becomes quite luminous but the first evidence of pressure release is observed 50-60 μsec after entry of the shock.

The early stages, at least, of the initiation process, appear to be a simple deflagration on the inner surface of bubbles, although the presence or absence of droplets inside the bubbles cannot be established. In any case, the process appears to be akin to a

deflagration on the surfaces within a bed of solid explosive. In the case of liquid explosives, and presumably single crystal solid explosives, defects or surfaces must be created and this can be accomplished by the passage of a shock wave followed by a rarefaction wave. Once the bubbles have formed, subsequent shocks associated with the ringing of the container or derived from incipient reaction sites can cause further heating of the liquid. Evans et al. (12) have shown that a region of elevated temperature, of volume approximately that of the bubble and downstream of it, will be created by the passage of a shock. These heated regions become especially important in the non-one-dimensional initiation case discussed here.

Low-velocity detonations are not limited to NG/EGDN; these have been observed in Cavea B and hydrogen peroxide-glycerol. Interestingly enough, LVD has not been observed in nitromethane. Since critical diameters are associated with LVD and for NG/EGDN the value is about 3/8 inch, higher than for the normal detonation, it was suspected that the absence of LVD in nitromethane in the usual 1-inch-diameter charge might be the result of its having a large critical diameter. However, no stable LVD has been observed even in 3-inch-diameter charges in steel pipe. The absence of LVD in nitromethane in the usual card-gap test charges now can be seen to explain the insensitivity of results for this explosive to changes of cup material or wall thickness.

In summary, the existence of LVD has many implications in the problem of defining the hazards of liquid explosives. Clearly of prime importance must be the realization that the true sensitivity of liquid explosives cannot be reliably determined by the standard card-gap test employing only a myopic witness plate. If the liquid explosive is capable of LVD, grossly misleading results in terms of the hazard of inadvertent initiation will be obtained from that test. It cannot be too strongly emphasized that the blast effect from an LVD will not be significantly less than that from a normal detonation. Larger fragments of the container will be projected at lower velocities in the case of LVD but the difference is scarcely enough to give aid and comfort to the safety engineer. The lower limit of shock strengths for the initiation of LVD has not been determined. As LVD is so evidently initiated by non-one-dimensional processes, the minimum amplitude of an incident shock necessary for initiation will be highly dependent on size, geometry, and material of the container, and shape, thickness, and point of entry of the incident shock. The explosive donor-attenuator combination of the card-gap test is inadequate to define this threshold. Other experimental approaches are under way, including projectile impact, to define the limiting conditions for LVD and to establish the mechanism of its initiation and propagation on a sounder basis.

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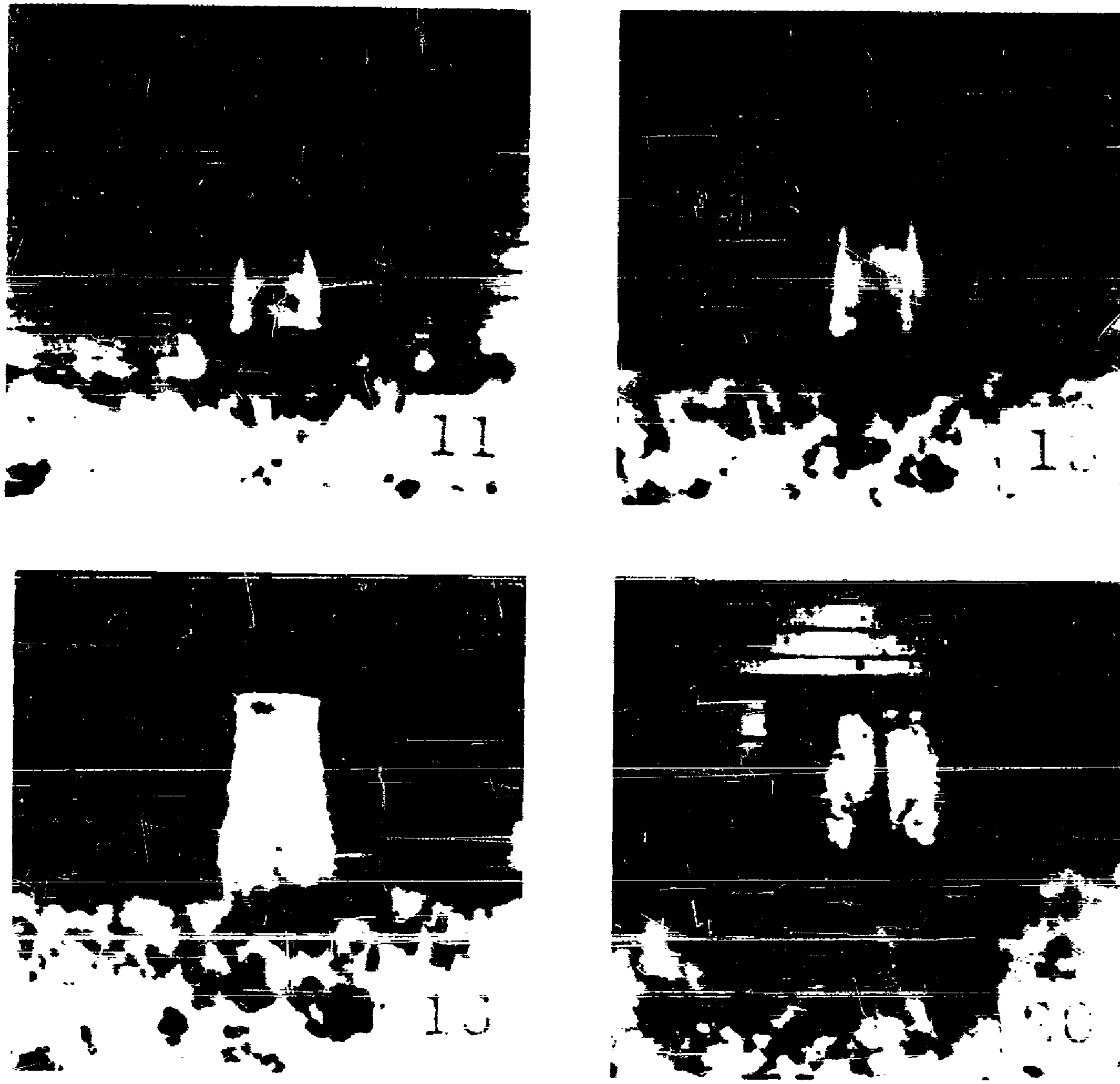

FIGURE 1. - Initiation of NG/EGDN in square Lucite and steel container.

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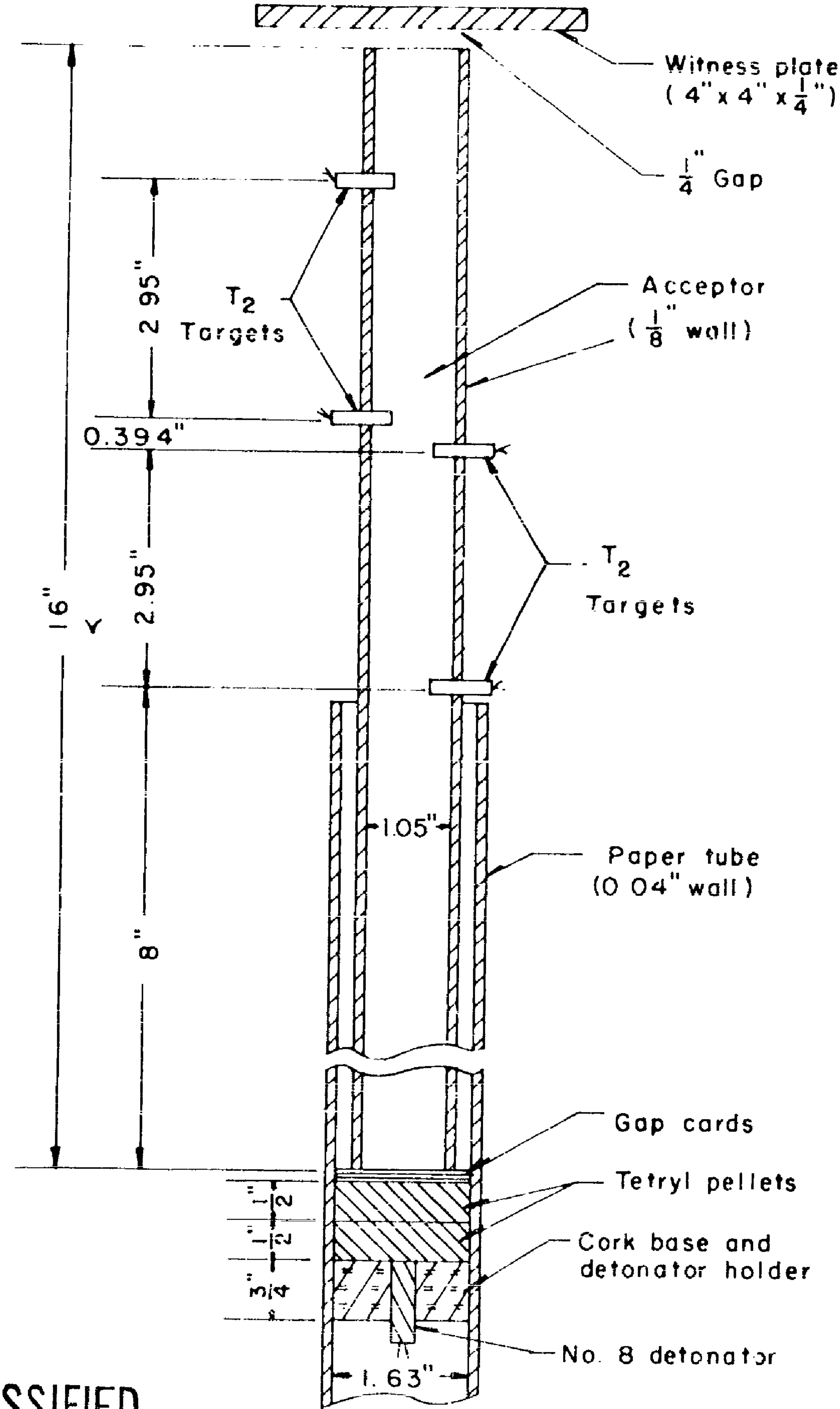

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FIGURE 2. - Modified card-gap charge.

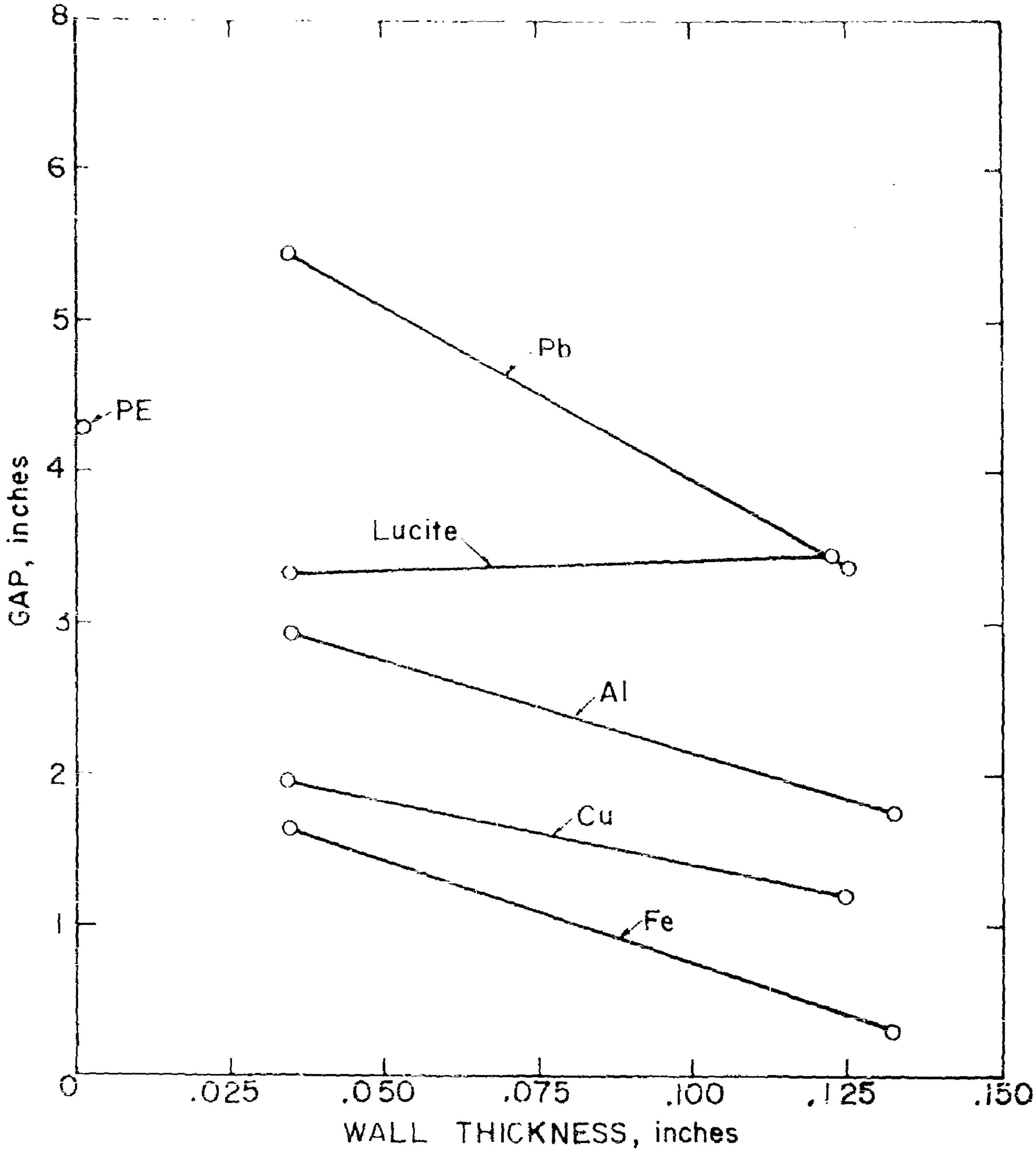

FIGURE 3. - Card-gap values of NG/EGDN in various containers.

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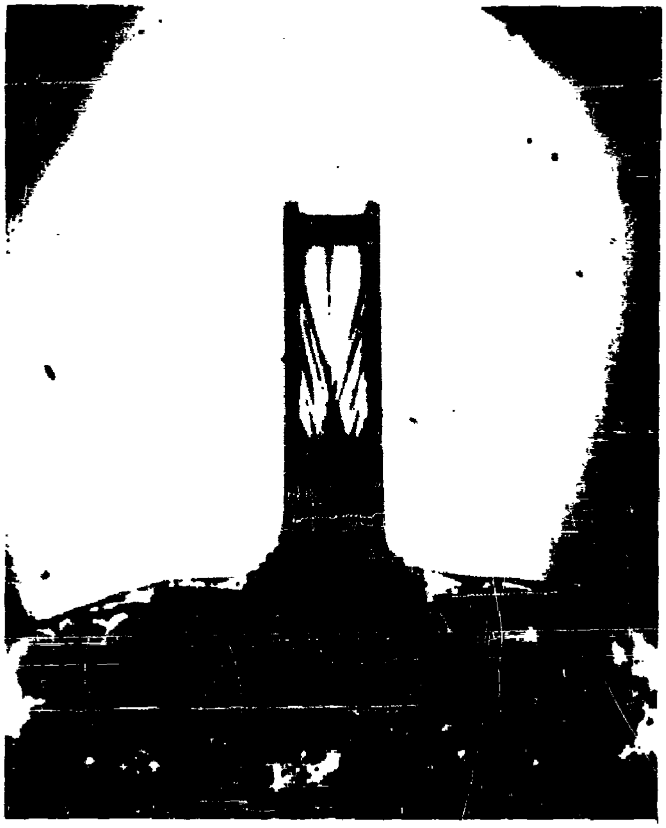

FIGURE 4. - Precursor waves in NG/EGDN contained in a steel-Lucite container.

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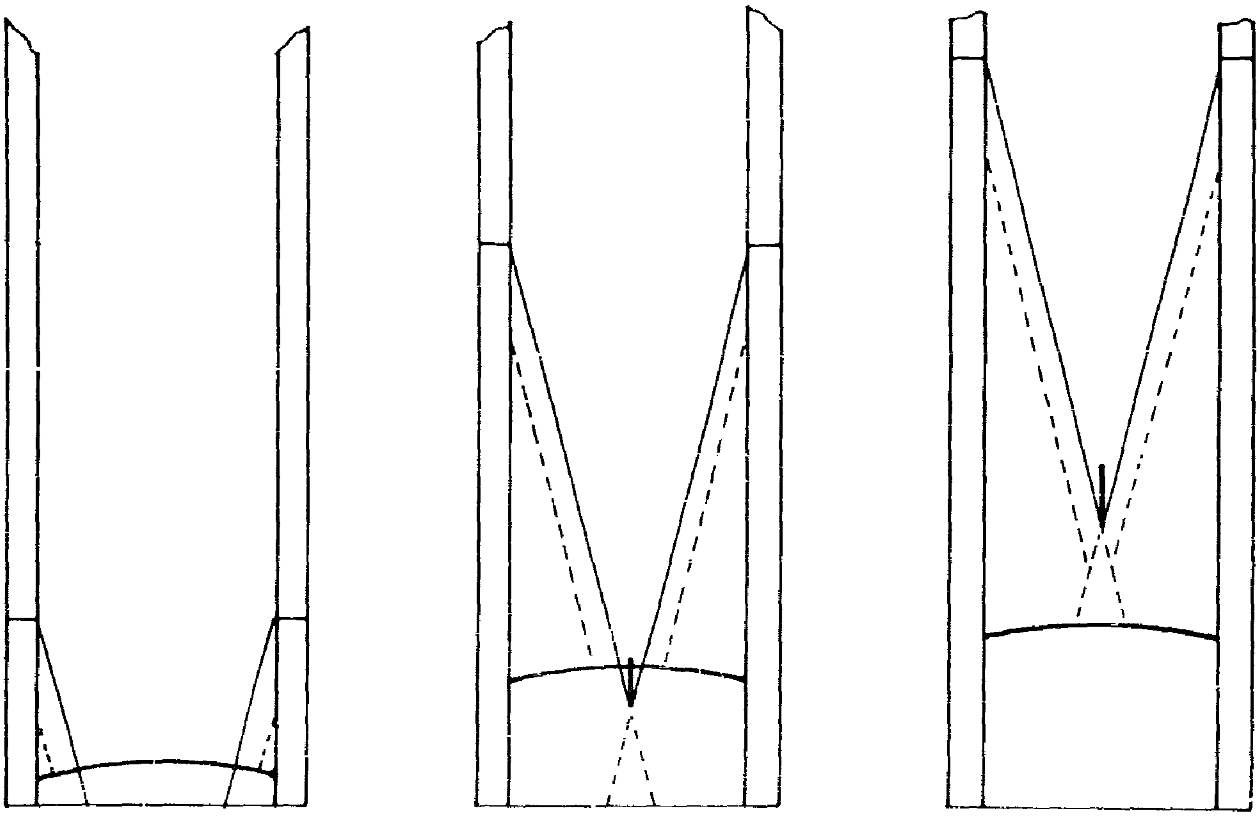

FIGURE 5. - Some possible precursor waves in NG/EGDN contained in a steel tube.

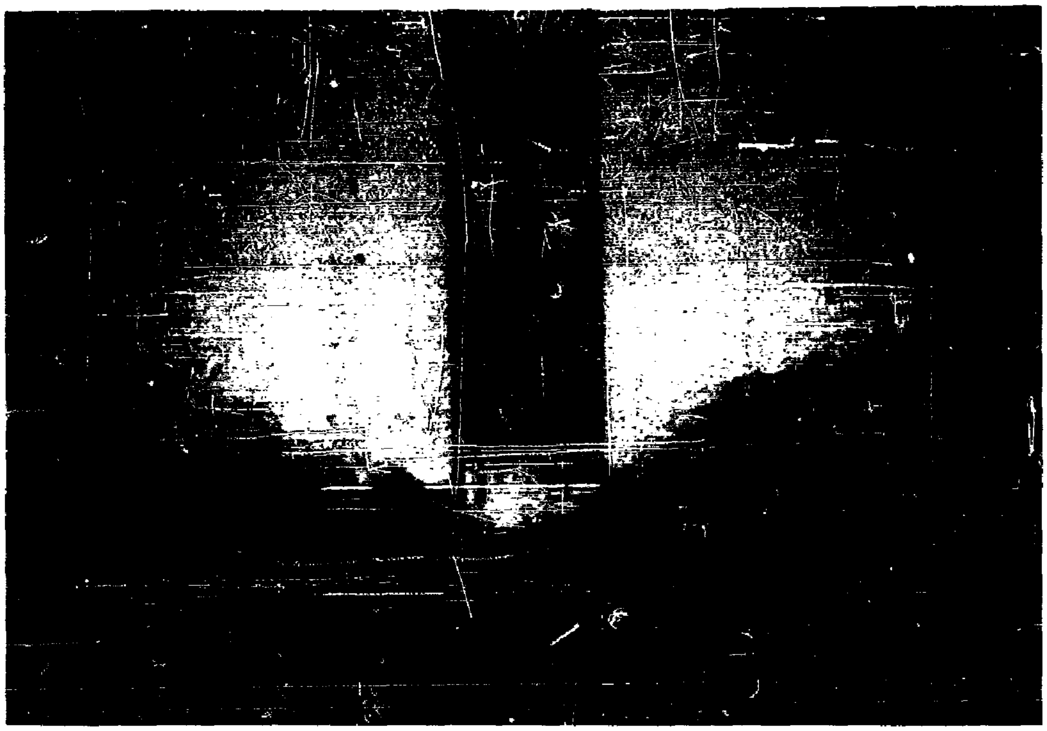

FIGURE 6. - Predetonation spike in NG/EGDN.

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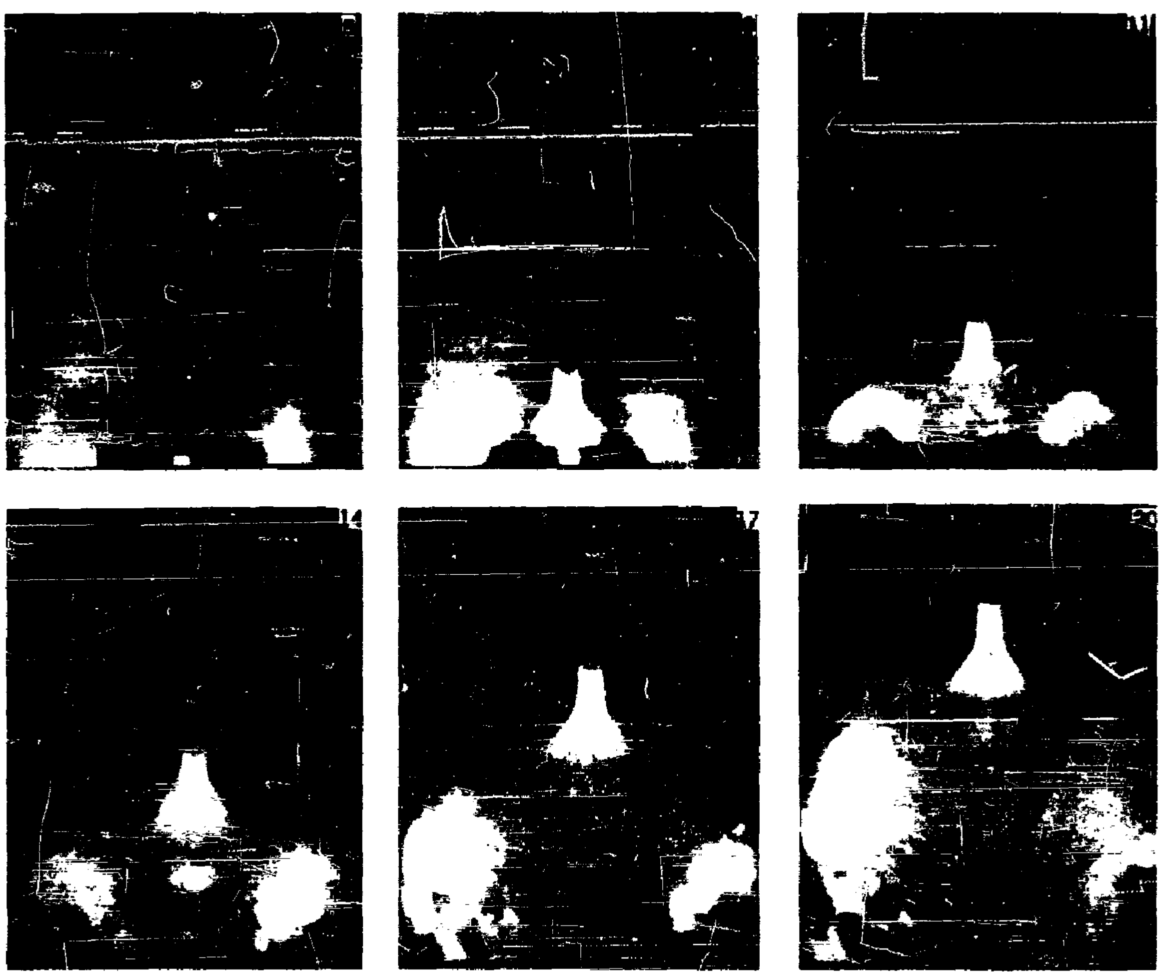

FIGURE 7. - Low-velocity detonation of NG/EGDN in a Lucite tube. Time between selected frames is 30 μsec.

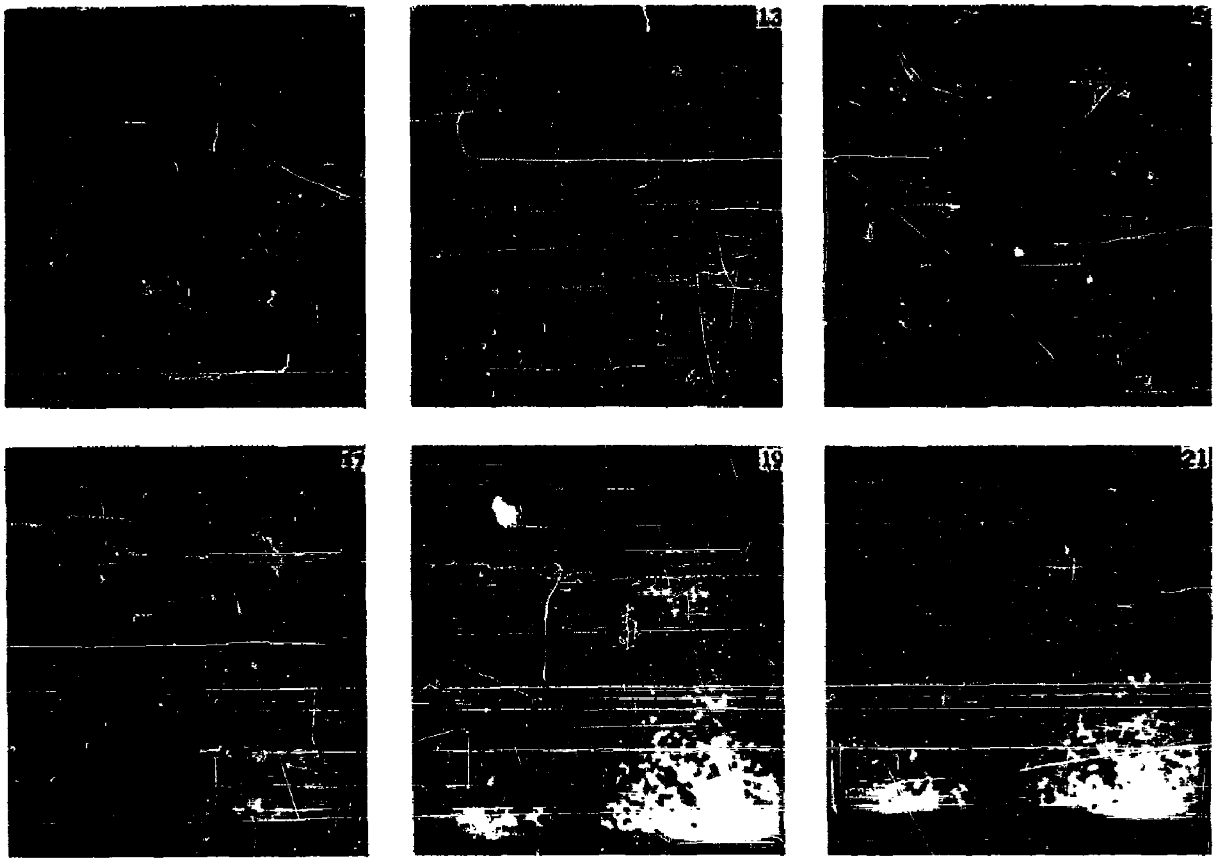

FIGURE 8. - Cavitation in water caused by explosive-derived shock. Time between frames is 8 μsec.

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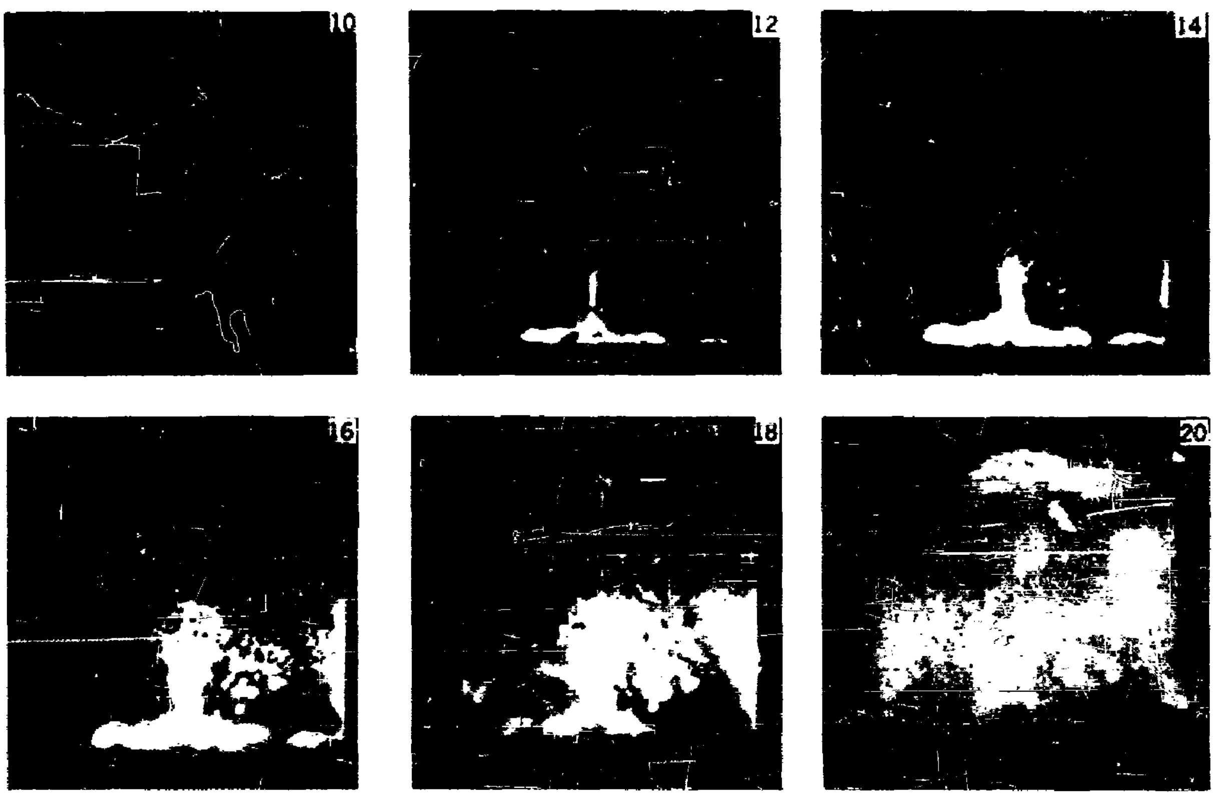

FIGURE 9. - Cavitation and luminous reaction in NG/EGDN caused by explosive-derived shock. Time between frames is 8 μsec.

Col. McCants: Ladies and gentlemen, this brings our 5th Seminar to a close. We wish to sincerely thank each of you for your very splendid participation; we also wish for you a very safe trip home and a safe and progressive year. We look forward to seeing you again.

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0 7 JUL 2000

MEMORANDUM FOR DDESB RECORDS

SUBJECT: Declassification of Explosives Safety Seminar Minutes

References: (a) Department of Defense 5200.1-R Information Security Program, 14 Jan 1997

(b) Executive Order 12958, 14 October 1995 Classified National Security Information

In accordance with reference (a) and (b) downgrading of information to a lower level of classification is appropriate when the information no longer requires protection at the originally level, therefore the following DoD Explosives Safety Seminar minutes are declassified:

a. AD#335188 Minutes from Seminar held 10-11 June 1959.
b. AD#332709 Minutes from Seminar held 12-14 July 1960.
c. AD#332711 Minutes from Seminar held 8-10 August 1961.
d. AD#332710 Minutes from Seminar held 7-9 August 1962.
e. AD#346196 Minutes from Seminar held 20-22 August 1963.
f. AD#456999 Minutes from Seminar held 18-20 August 1964.
g. AD#368108 Minutes from Seminar held 24-26 August 1965.
h. AD#801103 Minutes from Seminar held 9-11 August 1966.
i. AD#824044 Minutes from Seminar held 15-17 August 1967.
j. AD#846612 and AD#394775 Minutes from Seminar held 13-15 August 1968.
k. AD#862868 and AD#861893 Minutes from Seminar held 9-10 September 1969.

The DoD Explosives Safety Seminar minutes listed above are considered to be public release, distribution unlimited.

DANIEL T. TOMPKINS
Colonel, USAF
Chairman

Attachments:
1. Cover pages of minutes

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Auth: Chief Security Div. BSD
By: Maj. A.A. Correia, AFSC USAF
Date: 2 January 1964

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MINUTES
of the Fifth
EXPLOSIVES SAFETY SEMINAR
on
HIGH-ENERGY SOLID PROPELLANTS

Held at the
Miramar Hotel, Santa Monica, California
on
20-21-22 August 1963

This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18, U.S.C., Secs. 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

Armed Services Explosives Safety Board
Washington 25, D. C.

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